HIGH-RISE RESIDENTIAL BUILDING ENERGY ANALYSIS

IN SHANGHAI, CHINA

A Thesis

by

HONGYUN ZHOU

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Chair of Committee,	Jeff S. Haberl
Committee Members,	Juan-Carlos Baltazar-Cervantes
	Michael B. Pate
Head of Department,	Ward V. Wells

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ABSTRACT

The intent of this study was to reduce the energy consumption of an existing high-rise apartment in the warm and humid climate region of Shanghai, China by applying energy-efficient and cost-effective strategies.

To accomplish this, a typical high-rise apartment was selected as a case-study apartment. Its energy use and local weather data were collected and analyzed. A calibrated computer model of the case-study apartment was then constructed with the eQUEST program, and a series of strategies were applied to the base-case apartment including the building envelope, domestic appliances and HVAC systems. Both energy-efficiency and cost-effectiveness were analyzed and discussed.

The application of all the proposed energy-efficiency measures could save more than 40% of the total annual household energy use. However, many of the measures had a long payback period due to the high initial costs and low energy cost savings.

These findings are significant because they provide policy makers with a solution to better understand the growing residential energy use in Shanghai. The energy efficiency measures explored in this study should also provide policy makers with alternatives other than building more power plants, transmission and distribution systems.

DEDICATION

To my big and great family

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NOMENCLATURE

AAC	Autoclaved Aerated Concrete
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BDL	Building Description Language
BIPV	Building Integrated Photovoltaic
CDD	Cooling Degree Day
CFL	Compact Fluorescent Lamp
CMHC	Canada Mortgage and Housing Corporation
COP	Coefficient of Performance
CTFM	Conduction Transfer Function Method
CV (RMSE)	Coefficient of Variation of the Root Mean Square Error
DHW	Domestic Hot Water
DOE	Department of Energy
ECMs	Energy Conservation Measures
EEMs	Energy Efficiency Measures
EERE	Energy Efficiency and Renewable Energy
EF	Energy Factor
ESL	Energy Systems Laboratory
ETI	External Thermal Insulation
GDP	Gross Domestic Product
GHP	Geothermal Heat Pump
HAWT	Horizontal Axis Wind Turbine

HBM	Heat Balance Method
HDD	Heating Degree Day
HID lamp	High Intensity Discharge Lamp
HPWH	Heat Pump Water Heater
HVAC	Heating, Ventilation and Air-Conditioning
IBPSA	International Building Performance Simulation Association
ICEBO	International Conference for Enhanced Building Operations
IEQ	Indoor Environment Quality
IMT	Inverse Model Toolkit
ITI	Internal Thermal Insulation
IWEC2	International Weather for Energy Calculation 2.0
LBNL	Lawrence Berkeley National Laboratory
LED	Light Emitting Diode
MBE	Mean Bias Error
MVR model	Multi-Variable Regression models
NMBE	Normalized Mean Bias Error
PCM	Phase Change Material
PV	Photovoltaic
RMSE	Root Mean Square Error
SHGC	Solar Heat Gain Coefficient
SWH	Solar Water Heating
VAWT	Vertical Axis Wind Turbine

VBDD model	Variable-Base Degree-Day model
WFM	Weighting Factor Method
WWSHP	Waste Water Source Heat Pump

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1 INTRODUCTION

1.1 Background

Shanghai is located on the Yangtze River Delta in eastern China. It is a global city with worldwide influence in commerce, finance, culture, technology and transportation. Shanghai was the busiest container port in the world in 2012 (WSC, 2013). Also, it was ranked eighth among global financial centers in 2012 (Long Finance, 2012). The Gross Domestic Product (GDP) of Shanghai was $318.4 billion in 2012, which ranked first among all the cities in mainland China and represented 3.9% of China's GDP. Shanghai had the largest population of any city in mainland China with 23.8 million people, which represented 1.8% of China's domestic population in 2012. With less than 2% of Chinese population to support almost 4% of the Chinese GDP, Shanghai has been a powerful engine in China's economic development.

As Shanghai's economy grows, the standard of living has been greatly improved. On the other hand, the residential energy use in Shanghai is also climbing annually. According to the Shanghai Statistical Yearbook (Shanghai Bureau of Statistics, 2013), in the past ten years the total residential energy use increased by 116% from 140.4 trillion Btu in 2003 to 303.3 trillion Btu in 2012. During this period the annual energy use per person increased by 21% from 10.5 million Btu per person in 2003 to 12.7 million Btu per person in 2012. The primary reasons for the growth in energy use are: (1) the large increase in population; (2) the climate of Shanghai has significant heating and cooling requirements for buildings; and (3) as Shanghai's residents have increasing disposable income, they purchase more electric appliances and they use the appliances more often, which results in a growing residential electricity use.

As a result, the residential energy use has become a major obstacle in Shanghai's development. This growing energy use is challenging the city's ability to provide enough electricity to all the citizens. However, it is not practical to expand the energy supply capacity as required for several reasons: (1) the city has no plans for new power plants; (2) it is difficult to update transmission lines and distribution systems that serve the city; (3) there is limited space for new substations; and (4) more power plants means more air pollution from the fossil fuels, which is a threat to the public health. In the long run, without the control of its energy use, the city will end up with an increase in the cost of living and a decrease in the quality of life.

One potential solution to help solve the energy crisis in Shanghai is to decrease the residential energy use per capita. This can be achieved by: (1) a better understanding of the residential energy use for new and existing buildings; and (2) developing better solutions for efficient residential energy use. With these solutions, it is possible for Shanghai to have a sustainable development without economic and environment consequence in the future.

1.2 Purpose and Objectives

The purpose of this thesis is to improve the energy use efficiency with cost-effective strategies for a high-rise apartment in an existing building in Shanghai, China. To achieve this, the following objectives have been identified:

1) Analyze the weather conditions in Shanghai;
2) Develop a high-rise apartment model with the characteristics representative of a case-study multifamily building in Shanghai;
3) Investigate energy-efficiency measures that can be economically applied to the high-rise apartments in Shanghai.

1.3 Organization of the Thesis

This thesis is organized into six chapters.

Chapter I introduces the background the purpose and objectives of the research.

Chapter II reviews literature related to this research, including: an overview of the characteristics of the existing high-rise residential buildings and residential energy use in Shanghai; previous studies on energy-efficiency measures and renewable energy technologies for residential buildings; climate classification approach; a review of four whole-building energy simulation programs; and methods used for building model calibration.

Chapter III discusses the significance and the limitations of the research.

Chapter IV describes the methodology used to address each phase of this research, including: climate zone classification of Shanghai; the case-study apartment energy use simulation and calibration; energy-efficiency measures (i.e., insulation, window, lighting, appliances, air conditioning systems, heat pump water heater) simulation to the case-study apartment model.

Chapter V presents the results of the apartment model calibration, energy efficiency improvement from the measures applied to the case-study model, as well as cost analysis for the feasibility of energy-efficiency measures.

Finally, Chapter VI provides conclusion for this research and proposes recommendations for the future research.

2 LITERATURE REVIEW

2.1 Introduction

The categories of the literature review for this proposal are: 1) high-rise residential building characteristics in Shanghai; 2) residential energy use characteristics in Shanghai; 3) building energy efficiency techniques; 4) renewable energy technologies; 5) climate classification approaches; 6) analysis tools and techniques; and 7) methods for building model calibration.

The sources of literature include: journals (Architectural Record, ASHRAE Transactions, Building and Environment, Energies, Energy and Buildings, Journal of Building Physics, Refrigeration and Air Conditioning, Renewable Energy, Renewable and Sustainable Energy Reviews, Solar Energy, Sustainable Cities and Society, and Urbanism and Architecture,); conference proceedings (ICEBO, IBPSA, and Simbuild); books (Duffie and Beckman 2006, Eiffert and Kiss 2000, Hastings 2000, Ma 1993, Wenham et al. 2007, and Zhang 1993); publications by the Lawrence Berkeley National Laboratory (Winklemann et al. 1993), the Solar Energy Laboratory (Klein et al. 2004), the Energy System Laboratory (Haberl and Cho 2004), the Department of Energy (US DOE 2001, 2012, 2013a,b,c; EERE); magazine articles (Home Energy Magzine); related thesis (Bao 2000). The findings of the literature review are discussed in the following section.

2.2 High-Rise Residential Building Characteristics in Shanghai

This study requires defining a high-rise residential building with typical characteristics in order to identify the existing building energy use profiles, and to evaluate the energy-efficient and renewable energy strategies. The resources for the building characteristics information include: Shanghai high-rise housing development research (Bao, 2000), Design Standards for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone (JGJ 134-2010), housing statistical data (Shanghai Statistical Yearbook, 2012), as well as industrial energy efficiency standards for domestic hot water systems (GB20665-2006) and HVAC systems (GB 12021.3-2004).

The high-rise residential buildings in Shanghai have a long history. In the 1920s, Shanghai had the first high-rise residential building – Cathay Mansion – with 14 stories (Appendix A). From 1920 to 1949, there were 35 additional residential buildings were built with 8 to 20 stories. During this period high-rise housing was in its formative stage. However, from 1949, the central and local governments decided to invest in other industries, so the construction of high-rise housing was delayed until 1978. In 1979, with the national enforcement of the Reform and Opening Policy, the Shanghai government began to construct high-rise housing on a large scale to help alleviate the housing shortages and the overcrowded living conditions. This effort began the revitalization of high-rise housing. After 1992, commercial investment in housing was allowed in Shanghai, and residents were encouraged to use part of their incomes to purchase housing. With more and more non-state organizations participating in the development of housing projects, the housing market experienced a sharp rise, and high-rise housing construction started to boom (Li and Sun, 2009).

Since the 1990s, the major task for Shanghai housing construction was to accommodate the population from downtown by relocating them to new towns in the city (Appendix A), so that more construction could take place for commercial use (Ma, 1993). As a result, more industries were developed in urban areas, especially in the old city, which led to increasing costs for land use, especially in urban residential projects. As a result of the higher land use costs, high-rise housing construction became the dominant housing type in residential projects. At the same time, the higher land use costs made low-rise housing too expensive for most of Shanghai's residents.

Beginning in 1980s, all residential buildings were limited to eighteen stories based on the building codes. In the 1990s, buildings higher than eighteen floors needed extra fire protection facilities and infrastructure according to 1995 Code for Fire Protection Design of Tall Buildings (GB50045-95). Therefore, today eleven to fifteen story buildings are the main type of multifamily buildings. According to the Shanghai Statistical Yearbook (2012), 47% of buildings have eleven to fifteen stories, where the floor-to-floor height is usually between 2.8 to 3 meters (9.2 to 9.8 ft). In the early 1990s, the average building area for each high-rise housing unit was 60 to 65 m^2 (646 to 700 ft^2). However, with the accelerated development of housing market, and in response to clients' improving economic conditions, the size of housing units increased. In some new high-rise housing projects, the area of new large-size units could be as much as 130 m^2 (1,400 ft^2). Today, the layout of the household unit usually consists of two/three bedrooms, a living room combined with a dining room, a kitchen, one/two bathrooms and a balcony (Bao, 2000).

As of August 1, 2010, new residential buildings in Shanghai must comply with the new updated standard – the Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone” (JGJ 134-2010). This standard sets specific requirements for: (1) the building envelope such as conductivity, window-to-wall ratio, shading coefficients, etc.; (2) the indoor environment quality including indoor air temperature and air change rate; and (3) energy efficiency domestic HVAC systems and water heating systems.

2.3 Residential Energy Use Characteristics in Shanghai

According to the survey by Hu et al., (2013), the average household energy end use for Shanghai in 2006 was as follows: 41% of the end-use energy for lighting fixtures and domestic appliances; 23% for hot water; 21% for cooking; 12% for space cooling and 3% for space heating.

Therefore, lighting fixtures and domestic appliances used the most energy in this survey. For lighting fixtures, incandescent and fluorescent lamps are the most popular, only a small number of light-emitting diode (LED) lights were used (Chen et al., 2009). One reason for this situation is that the residents in Shanghai were not aware of the economic and social benefits of energy efficient lighting. For domestic appliances, based on the data from Shanghai Statistical Yearbook (2012), people tended to purchase more electric appliances and were willing to use the appliances more often than ever before.

In terms of water heating: 98% of residences are equipped with individual water heaters. Among these, 80% families used gas water heaters, 18% used electricity water heaters, and only 2% used solar water heaters (Hu et al., 2013).

The 3% end-use energy for space heating in Shanghai is quite low compared to 45% in US residential buildings (Buildings Energy Data Book, 2013). One reason for this is that during the heating season in Shanghai, people prefer to wear more clothing to keep warm rather than use heating systems at home. As a result, the space heating energy use is very low in Shanghai and the indoor thermal environment remain outside ASHRAE comfort zone in the winter for a large period of time (Yoshino et al., 2004).

Although the residential energy use currently remains at a low level in Shanghai compared to the US, household energy consumption in Shanghai is growing every year. This is partially due to an increase in disposable income, which allows the residents in Shanghai to purchase more domestic appliances. Today, people not only possess more appliances than ever before, but also tend to use them more (Shanghai Statistical Yearbook, 2012).

2.4 Energy Efficiency Measures for High-Rise Residential Buildings

The previous literature about active and passive building energy efficient strategies was also investigated to minimize residential energy use. The sources reviewed included: Sandineni et al. (2011), Duffie and Beckman (2006), Concrete Homes (2012), Ciampi et al. (2003), Athienitis et al. (1997), Bahaj et al. (2008), Gustavsen et al. (2008), Mayfield (2000), Alvarado et al. (2009), and Balaras (1996) for building envelope measures; Geltz (1993), Hu et al. (2013) and the Energy-saving Huimin Project (2012) for lighting and appliances measures; Bauman et al. (2001), DOE (2012) and Roth et al. (2007) for Mechanical systems and equipment measures.

2.4.1 Building Envelope

Opaque walls are the predominant component in the building envelope for the purpose of providing thermal and acoustic comfort inside buildings. The technologies for improving thermal performance of opaque walls include: Trombe-walls, autoclaved aerated concrete (AAC) walls, ventilated walls and Phase-change materials (PCMs) for walls. For the northern hemisphere, in cold climates, a south-facing Trombe-wall traps and transmits the daytime solar energy into the building for night time space heating (Duffie and Beckman, 2006). Light weight concrete such as autoclaved aerated concrete (AAC) has higher thermal resistance than normal concrete by introducing aluminum powder to generate miniscule air bubbles in the concrete. AAC has a great potential in concrete construction (Concrete Homes, 2012). A ventilated or double skin wall has an air gap between two layers of masonry wall braced with metal ties. Ventilated walls are most commonly used to enhance the passive cooling of buildings. With a carefully designed ventilated wall, summer cooling energy savings can reach 40%. However, poor quality construction can introduce thermal bridge issues (Ciampi et al., 2003). The Phase-Change-Materials (PCMs) incorporated into light weight wall structures also help to improve the thermal storage capacity while minimizing the thermal mass. In PCMs, heat is absorbed or released with each phase change. Studies on PCM-based composite walls showed a decrease in maximum room temperature and lower heating demand at night (Athienitis et al., 1997).

Fenestration refers to openings in the building envelope that are usually windows and doors that transmit visible light. Fenestration plays a major role in determining the thermal comfort and illumination levels in the building. The annual heat gain/loss by a window is dependent on factors including window thermal conductivity (U-value), window solar heat gain coefficient (SHGC), window orientation, climate conditions, etc. (Sadineni et al., 2011). The available technologies for high performance fenestration design include: 1) high efficiency glazing materials such as aerogel, vacuum, photochromic, thermochromic, electrochromic and switchable reflective glazing with Low-E coating or spectrally-selective coatings (Bahaj et al., 2008). However, these glazing materials are currently too expensive for commercial use. 2) low conductance frames and window spacers minimize thermal bridging and infiltration losses of the fenestrations (Gustavsen et al., 2008); 3) solar shading devices such as overhangs, vertical fins, decks and porches, awnings, light shelves, screens, blinds and rolling shutters (Mayfield, 2000).

Roofs also play an important role in high thermal performance buildings: (1) Insulation systems are very important to improve roof thermal performance. Roof insulation has the potential for reducing both cooling and heating loads. Laboratory experiments demonstrate that a well-designed roof with the proper insulation level can reduce heat absorption, heat conduction and reduce the exterior temperature of the roof (Alvarado et al., 2009). (2) Solar reflective roofs consist of roof materials or coatings with high solar reflectance and high infrared emittance, which decreases the roof surface temperature in the summer and reduce building cooling loads.

Building integrated photovoltaics (BIPV) provide a feasible way to use building surfaces to facilitate energy production as well as to protect the building envelope against weather changes. With the substantial decrease in PV costs, this type of roof could have widely application (Sadineni et al., 2011).

2.4.2 Lighting and Appliances

Lighting energy saving measures include: using energy efficiency lamps (including compact fluorescent lamps (CFL), high intensity discharge lamps (HID), and lamps with light-emitting diodes (LED)), task oriented lighting, small scale fixtures, occupancy sensors, dimmers and timers (Geltz, 1993). Domestic appliances such as refrigerators, washers, dryers, cooking stoves and air conditioners are the most significant energy consumption equipment in a residence. Based on the survey by Hu et al. (2013), illumination and other appliances (excluding air conditioner) represented 41% of total household energy consumption in Shanghai in 2006. Therefore, decreasing the energy use from these end uses will have a significant impact on reducing household energy use in Shanghai.

In 2012, the Chinese government started the "Energy-saving products Huimin Project". The purpose of this project is to promote high energy-efficiency products as well as to reduce the green-house gas emissions produced at the coal fired power plants that provide the electricity. The products include: energy efficient lighting equipment, refrigerators, clothes washers, domestic water heaters, flat screen television, personal computers, and high efficiency air conditioners. Purchases of products with higher energy efficiency than the market average will qualify for economic subsidies (Energy-saving Huimin Project, 2012).

2.4.3 Mechanical Systems

Technologies for heating, ventilation and air-conditioning (HVAC) systems were also reviewed for residential buildings, including: ductless mini-split heat pumps (mini-splits) and radiant cooling/heating systems. Mini-splits are flexible systems for heating and cooling individual rooms. By conditioning only occupied rooms, mini-splits can save energy and costs in rooms that do not need heating and/or cooling. With no ductwork, energy losses are greatly decreased in mini-split systems (DOE 2012a).

Radiant heating/cooling systems usually have hot or cold water circulating in pipes embedded in the building's concrete structure or in specialized concrete panels. Radiant systems are only responsible for sensible cooling loads, and must be carefully controlled in the cooling mode to avoid drop below the interior dewpoint temperature. The systems have great energy saving potentials, because they can use higher temperatures for cooling and lower temperatures for heating than conventional systems, and can be combined with low-grade heating systems for additional savings. Condensation in the cooling mode and difficulties with control are the main drawbacks of the systems. In the past decades, these systems have seen some applications in residential and commercial buildings in China (Hu and Niu, 2012).

2.5 Renewable Energy Technologies for High-Rise Residential Buildings

The renewable energy technologies applicable to residential buildings include: (1) Solar electric systems (Effert and Kiss, 2000; Solar Plaza, 2011; Solar Plaza, 2012; and CMHC, 1998); (2) Solar thermal systems (CMHC, 1998; Hastings, 2000); (3) Wind power systems (EERE, 2013; Lu and Ip, 2009; Sharpe and Proven, 2010; and Chong et al., 2012); (4) Geothermal technologies (DOE, 2013a; 2013b; 2013c); and (5) Waste water source heat pump systems (Chen et al., 2006; Kahraman and Celebi, 2009; and Baek et al., 2005).

2.5.1 Solar Electric Systems

Solar electric systems, also called photovoltaic systems (PVs), directly convert short-wave solar radiation into usable electricity. A solar cell is the basic element in a PV system. Series of solar cells are packaged together to form a PV module; when modules are wired together in a single mount, they are called a panel; two or more panels can be wired together to create a PV array. These arrays also require a Balance of System (BOS), which handles the appropriate DC to AC conversion and safety features (Effert and Kiss, 2000).

The PV panels have different efficiency based on materials: (1) a mono-crystalline silicon panel has the highest efficiency of 15%-18%; (2) a poly-crystalline silicon panel has the efficiency of 13%-16%; (3) a thin-film panel has the lowest efficiency of 5%-8%. Although thin-film PV is the least expensive, and it has great flexibility since it can be applied to different types of surfaces. Based on the manufacturers' product data, the world's top 10 commercially available mono-crystalline silicon solar PV cells have the cell efficiency of 19.1%-22.5% (Solar Plaza, 2012); the world's top 10 commercially available poly-crystalline silicon solar PV modules have the module efficiency of 15.24%-16.0% (Solar Plaza, 2011).

Building-Integrated PV system (BIPVs) is a new trend of PV development. The PV cells are incorporated into a building's elements such as roofs, shading elements, claddings and curtain walls (CMHC, 1998). BIPVs not only supply electricity for domestic use, but also provide a portion of building envelope, which helps to save costs.

2.5.2 Solar Thermal Systems

Solar systems for heating include solar water heating systems and solar air heating systems, where solar energy is utilized to heat water for domestic use and/or heat air for space heating. Solar water heating systems (SWHs) have water passing through solar collectors for heating that is then stored in a storage tank for domestic use. The indirect systems are often needed in climates where freezing condition occur in the winter. SWHs can be divided into direct and indirect systems. The former has potable water circulation through the collectors; the latter uses a heat exchanger that separate the potable water from the heating fluid that circulates through the collector. SWHs can also be divided into passive and active systems. The former relies on heat-driven convection or heat pipes for fluid circulation in the system; the latter has pumps to circulate fluid in the system (DOE, 2012a). Solar air heating systems offer another potential for space heating. Most systems use a solar collector to heat the air and a storage medium. The space is then heated as air is circulated through the thermal storage before heating the space (Hastings, 2000).

2.5.3 Wind Power Systems

Wind power systems convert kinetic energy from the wind into mechanical energy. When the mechanical energy is used to produce electricity, the wind power system is called a wind turbine. Wind turbines have two general types: horizontal axis wind turbines (HAWTs) with its blades rotating on an axis parallel to the ground; vertical axis wind turbines (VAWTs) with its blades rotating on an axis perpendicular to the ground. HAWTs have a high efficiency in energy conversion, but do not work well in turbulent winds (i.e., they must be protected). Compared to HAWTs, VAWTs have a relatively lower efficiency, but work better where wind conditions are not consistent. VAWTs are primarily used in small projects and residential applications (Energy Efficiency and Renewable Energy, 2013).

Studies have identified that there are potential benefits from the theoretical augmentation of wind flow around high-rise buildings (Lu and Ip, 2009). By investigating the wind aerodynamics and wind flows over and around buildings, based on local meteorological data and local building characteristics, the concentration effect of air flow around buildings and the height of buildings can enhance wind power utilization by increasing the wind power density and/or wind speed in specific areas where the wind turbine is then placed. Some research on building integrated wind turbine tries to provide both augmented air flow and improved visual integration into new and existing buildings, but the vibration of the wind turbines, especially the HAWTs, is still a problem (Chong et al., 2012).

2.5.4 Geothermal Heat Pump Systems (GHPs)

The stable ground temperature is an ideal resource for heating in the winter as well as cooling in the summer. Geothermal heat pump systems (GHPs) use the constant-temperature ground heat as the heat exchange medium instead of the fluctuating outside air, which can become too cold in the winter and too hot in the summer for efficient operation. There are four basic types of geothermal heat pump systems. Three of which are closed-loop and one is an open-loop. Closed-loop systems can have horizontal, vertical and pond/lake configuration. Most GHPs circulate an antifreeze solution through a closed loop, which is buried in the ground or submerged in water. A heat exchanger transfers heat between the antifreeze solution in the loop and the refrigerant in the heat pump. The open-loop system uses wells or surface water as the heat exchange fluid that circulates directly through the GHPs. The open loop system may have water quality issues, and local water discharge regulations that must be met. According to statistics, geothermal systems can save 30% - 50% heating/cooling costs (DOE, 2013a).

2.5.5 Waste Water Source Heat Pump Systems (WWSHPs)

Urban waste water is also becoming an ideal heat source for heat pumps due to its temperature stability compared to the outdoor air. In China, in the winter, the temperature of the waste water is typically in the range of 12 - 20°C (53.6 – 68°F). This low-level heat in the waste-water can be extracted for space heating using a heat pump. In the summer, the temperature of the waste water is in the range of 20 - 25°C (68 - 77°F), which allows the heat from the space to be absorbed by the water for space cooling using a heat pump (Chen et al., 2006).

WWSHPs mainly include: a waste water tank, a heat pump (i.e., an evaporator, a compressor, a condenser and an expansion valve) and an energy storage tank. In the heating season, the refrigerant in the heat pump absorbs heat from the waste water tank and release the heat from the heat pump to the energy storage tank. The process is reversed in the cooling season (Kahraman and Celebi, 2009). Baek et al., (2005) discovered that on district heating and cooling, WWSHP had less energy use with higher annual average operating Coefficient of Performance (COP) comparing with conventional air-source heat pumps.

2.6 Climate Classification Approach

Climate zone classification is an important task in building codes energy analysis. Local weather condition influence many aspects of building energy performance, including: the ambient air temperature that determines the heating and cooling loads, as well as wind speed and direction, solar radiation, and the hours of day-light that affect the auxiliary lighting load (Radhi, 2009). Therefore, it is necessary to identify the climate characteristics of the target city when performing a building energy analysis.

The approach for climate classification by Briggs et al., (2003a, 2003b) has been reviewed. In this climate zone classification system, major climate types were defined as humid, dry and marine based on local annual precipitation and mean temperature. Under these major climate types, eight thermal zones were developed based mostly on 1,800 degree-day bands of 65°F HDD and 50°F CDD. ASHRAE Standard 90.1 has adopted this climate zone classification system since 2004. According to tables listed in ASHRAE Standard 90.1-2004, Appendix B, Shanghai is located in Climate Zone 3. Therefore, when referencing this standard, the buildings in Shanghai should comply with the criteria for this climate zone.

2.7 Analysis Tools and Techniques

Over the past 50 years, a wide variety of building energy simulation programs have been developed and used. Currently, whole-building energy simulation programs are important tools in the design and analysis of HVAC systems, because they provide users with key building performance indicators such as the energy use, energy cost and electric demand, as well as predict indoor air temperature, and humidity levels. The whole-building energy simulation programs reviewed include: DOE-2 (Winklemann et al., 1993), EnergyPlus (Crawley et al., 2004), TRNSYS (Klein et al., 2004), and eQUEST (Hirsch and Associates, 2010).

DOE-2 software was developed by Lawrence Berkeley National Laboratory (LBNL) mainly with funding from the United States Department of Energy (USDOE). The first version of DOE-2 was released by the LBNL in 1978. DOE-2 predicts the hourly energy use and energy cost of a building given hourly weather information, building geometry, HVAC and material description, as well as utility rate structures. DOE-2 has one subprogram to translate the user’s input command (BDL Processor), and four simulation subprograms (LOADS, SYSTEMS, PLANT and ECONOMICS) that are executed in sequence. The program uses: 1) the Response Factor Method (RFM) to calculate the transient heat transfer through multi-layer walls and roofs (Stephenson and Mitalas, 1967); and 2) the Weighting Factor Method (WFM) to calculate the overall heat transfer within a thermal zone (Winklemann et al., 1993). DOE-2 has been widely used for energy performance evaluation of buildings and it has been extensively validated for accuracy and consistency (Haberl and Cho, 2004).

EnergyPlus is a more recently developed modular, energy analysis and thermal load simulation program, which was a released by LBNL in 2001. In the simulation process in EnergyPlus, loads are calculated at a user-specified time step. The results are then used to size the system and plant, as well as for occupant comfort and health calculations (Crawley et al., 2008). The program uses: 1) the Conduction Transfer Function method (CTF) to calculate the heat transfer through multi-layer walls and roofs; and 2) the Heat Balance Method (HBM) to calculate overall the overall heat transfer within a thermal zone (Pan et al., 2008).

TRNSYS was developed by the Solar Energy Laboratory (SEL) at the University of Wisconsin, primarily for solar thermal system design (Klein, 1973). It is a transient system simulation program with a modular structure that allows simulation of complex energy systems by configuring and assembling a series of smaller components (Klein et al., 2004). The TRNSYS library of components include: solar thermal and PV systems, wind turbines, cogeneration, fuel cells as well as low energy buildings and HVAC systems with advanced design features (natural ventilations, slab heating/cooling, double façade, etc.).

eQUEST is a user friendly building energy use analysis program that uses the DOE-2.2 simulation engine, which is based on DOE-2 program. eQUEST can simulate and graphically display the implementation of energy efficiency measures, which is helpful to improve building performance and optimize energy use (Hirsch and Associates, 2010). Since eQUEST is easy to use, and the DOE-2.2 engine can accurately simulate the whole-building energy performance, this research will use the eQUEST software for the case-study building energy use analysis and improvement.

For renewable energy analysis programs, the F-Chart and PV F-Chart were reviewed. These are simplified programs for the design and analysis of solar thermal and photovoltaic systems, respectively (Klein and Beckman, 1983, 1985). F-Chart and PV F-Chart use monthly average weather data, calculated hourly solar data, and require a general description of the solar system to predict long-term system performance.

2.8 Methods for Building Model Calibration

Building model calibration is mainly used for: (1) providing insight to an owner about a building's thermal and electrical load shapes with utility billing data (Sonderegger et al. 2001); (2) calculating a building's electricity use including baseline, cooling and heating energy use which are calibrated to the utility bills in order to predict the impact of different energy-efficiency measures on the total electricity use (Mayer et al. 2003); and (3) support for investment-grade recommendations about cost-effective ECMs to specific buildings and determining their payback (Reddy, 2006).

Calibration techniques for building simulation have been reported by many researchers and institutes over the years including: Pedrini et al. (2002), Kaplan et al. (1990), Norford et al. (1994), Haberl and Abbas (1998a, 1998b), Haberl and Bou-Saada (1998), Soebarto (1997), Kreider and Haberl (1994), Kissock et al. (2004), and ASHRAE Guideline 14 (2002).

Pedrini et al. (2002) developed a calibration methodology involving three steps: using as-built drawings, walk-through visits, and electric and thermal measurement. This method was used to calibrate 15 office building models in DOE-2 simulation program.

Kaplan et al. (1990) proposed short-term measured data to perform the model calibration against a whole year's analysis. The short term periods recommended were one hot weather month, one cold weather month and one moderate weather month. Kaplan noted that calibrating the model in a moderate month was very difficult due to the unpredictability of HVAC operation schedule and the instability of weather condition. Thus, the measured data under a hot month and a cold month were found to provide the best results to calibrate the models.

Norford et al. (1994) presented the calibration process of a low-energy office building based on the DOE-2 model. The work showed that the nature of the occupants' business (i.e. energy intensive facilities that occupants use), occupants' behavior on lights and office equipment use, and the conditioning equipment operation manner had enormous impact on the building energy use. These are the major parameters in calibration.

Haberl and Abbas (1998a, 1998b) used graphical method to analyze the large amounts of hourly building energy use data, check for errors, and establish time and temperature related trends over a large period of time. Haberl and Bou-Saada (1998) developed hourly comparison techniques, including: a temperature bin analysis to improve hourly x-y scatter plots, a 24-hour weather-daytype bin analysis to allow for the accurate evaluation of hourly temperature and schedule- dependent comparisons, and a 52-week bin analysis to facilitate the combined graphical and statistical evaluation of long-term trends.

Soebarto (1997) suggested that, in case resources are limited, blink tests or on/off tests could be used to measure electricity end-use. A series of tests are performed when groups of end-use loads are turned on and off in a controlled sequence. At the same time the incremental power readings from a data recorder provide the necessary end-use information. Soebarto presented the results of two case studies using monthly utility bills with building drawings, site visits, hourly monitored whole-building electricity use and blink tests. The paper showed that only two-to-four weeks of monitoring at any period of the year was enough to provide accuracy of the model, CV(RMSE) between the model and utility data is as low as 6.7% for hourly data.

In the previous studies a number of statistical calibration methods have been used as goodness-of-fit indicators including percent difference, mean bias error (MBE), root mean squared error (RMSE), and coefficient of variation of the root mean square error (CV(RMSE)) (Kreider and Haberl, 1994). According to ASHRAE Guideline 14-2002 (2002), models are declared to be calibrated if they produce normalized mean bias error

(NMBE) of 10% or less and CV(RMSE) of 30% or less when using hourly data, or 5% and 15% with monthly data, respectively.

Kissock et al. (2004) developed the ASHRAE Research Project 1050-RP, which created an Inverse Model Toolkit (IMT) for building energy analysis. The IMT was originally developed to calculate the energy savings after building energy conservation retrofits. When pre-retrofit data are available, the IMT can calculate a regression model of the building energy use as a function of influential variables, such as weather, occupancy, etc. The regression model can then be used to predict how much energy the building would have consumed in the post-retrofit period if the building had not been retrofitted. Energy savings are then calculated as the difference between the predicted energy use and the measured energy use in the post-retrofit period. The IMT can calculate several types of regression models, including: (1) Mean models; (2) Two-parameter heating or cooling models; (3) Three-parameter heating or cooling models; (4) Four-parameter heating or cooling models; (5) Five-parameter heating and cooling models; (6) Multi-Variable Regression (MVR) models; (7) Variable-Base Degree-Day (VBDD) models; and (8) combination of MRV, change-point or VBDD models. In this research, the IMT was used to create a baseline model to help analyze the building energy performance, the details are discussed in Chapter 5.1.1.

2.9 Summary of the Literature Review

This literature review presented an overview of: the characteristics of the existing hig-rise residential buildings and residential energy use in Shanghai; previous studies on energy-efficiency measures and renewable energy technologies for residential buildings; climate classification approach; a review of four whole-building energy simulation programs; and methods used for building model calibration.

The review showed that nearly half existing buildings have eleven to fifteen stories. Also, it was determined that a typical household unit consists of two/three bedrooms, a living room combined with a dining room, a kitchen, one/two bathrooms and a balcony. Finally, the review identified an updated design standard for energy-efficiency residential buildings in hot summer and cold winter zone became a guideline for new apartment buildings in Shanghai. This standard sets the requirement for building envelope, indoor environment quality and energy efficiency for domestic HVAC systems and hot water systems.

The review included a 2006 survey in Shanghai that showed 41% of the average household end-use energy was for lighting fixtures and domestic appliances; 23% for hot water; 21% for cooking; 12% for space cooling and 3% for space heating. The review also showed 80% families prefer natural gas water heaters, 18% families use electricity water heaters, only 2% users choose solar water heaters. In addition the review showed the residents preferred to sacrifice the thermal comfort rather than turning-on their HVAC systems in a relatively cold/hot season. Finally, the review showed that although the energy use is at a low level in Shanghai, the household energy use is growing every year, because with higher disposable income, people are willing to pay more to make their life more comfortable.

The review of energy efficiency measures applicable to residential buildings included the building envelope, more efficient lighting and efficient mechanical systems

The review of renewable energy technology applicable to high-rise residential buildings included: (1) solar electric systems, (2) solar thermal systems, (3) wind power systems, (4) geothermal heat pump systems, and (5) waste water source heat pump systems.

The review of the climate zone classification approach showed that annual precipitation, mean temperature and degree day method were used to identify major climate type and thermal zone for target area.

The review of whole-building simulation program included: DOE-2, EnergyPlus, TRNSYS, and eQUEST. eQUEST was appropriate for the whole-building simulation and analysis in this research.

Finally, a review of the simulation calibration methods included architectural rendering, walk-through visits, and onsite measurements. In addition, several promising analysis methods were identified, including: graphical method, blink tests, and statistical methods to indicate goodness-of-fit of a calibrated model.

3 SIGNIFICANCE AND LIMITATIONS OF THE STUDY

3.1 Significance of the Study

This study presents a step-by-step method to simulate and calibrate a high-rise apartment in Shanghai, China, and includes a series of cost-effective energy-efficient measures proved to be applicable to the high-rise apartment. This research is significant because very few such studies have been previously developed and published for shanghai, and it offers the policy makers a solution for the energy crisis that the city is confronting with.

3.2 Limitations of the Study

The current study only focused on one apartment in an existing high-rise residential building in Shanghai, since the apartment information and energy use data for the other families in the building were not available. Therefore, only the energy use for the apartment was analyzed using specific assumption about the indoor environment quality (IEQ). An analysis of the impact of the research on the IEQ was not performed. New development in renewable energy technologies such as solar thermal/electric and wind turbine were also not discussed in the research.

4 METHODOLOGY

4.1 Overview of the Methodology

The tasks of this study are to: 1) analyze the weather conditions of Shanghai; 2) create an eQUEST model with the characteristics representative of a case-study apartment in a high-rise building in Shanghai; 3) investigate energy-efficiency measures that applicable to the case-study apartment; (4) perform economic analysis on the energy-efficiency measures applied to the case-study apartment.

4.2 Weather Condition of Shanghai

The climate classification approach by Briggs et al., (2003a, 2003b) was used for this research. Using this approach, the climate classification for Shanghai was determined by the average annual temperature and precipitation. To accomplish this, the measured meteorological data of Shanghai were retrieved from the monthly climate data (China Meteorological Administration, 2010), and the average monthly temperature and precipitation were calculated using thirty year measured data from 1971 to 2000, as shown in Table 4.1. This analysis showed the climate classification for Shanghai to be Humid (A).

Table 4.1 Shanghai Average Monthly Temperature and Precipitation from 1971 to 2000

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Year
T_{mean} ℃ (F)	4.7 (40.5)	6.0 (42.8)	9.2 (48.6)	14.7 (58.5)	20.3 (68.5)	23.8 (74.8)	28.0 (82.4)	27.8 (82.0)	24.4 (75.9)	19.2 (66.6)	13.5 (56.3)	7.8 (46.0)	**16.6 (61.9)**
Precipitation cm (inch)	5.06 (1.99)	5.68 (2.24)	9.88 (3.89)	8.93 (3.52)	10.23 (4.03)	16.96 (6.68)	15.63 (6.15)	15.79 (6.22)	13.73 (5.41)	6.25 (2.46)	4.62 (1.82)	3.71 (1.46)	**116.47 (45.86)**

The ambient thermal conditions for Shanghai were further determined using degree days. To accomplish this, five years (2009-2013) of data were retrieved from the Shanghai Hongqiao Weather Station (ZSSS) (Degree Days, 2014). The analysis showed that Shanghai is located in the Warm Climate Zone. Therefore, the climate zone and type for Shanghai was determined to be Warm-Humid (3A). ASHRAE 90.1 has listed this climate classification system since 2004. Therefore, if using ASHRAE 90.1, the new buildings in Shanghai should comply with the requirements for Climate Zone 3A.

An hourly weather file for Shanghai is required for a whole-building energy use simulation and calibration. The hourly data of the weather file included: dry bulb temperature, dew point temperature, wind speed, wind direction, as well as solar radiation and illuminance calculated from the earth-sun geometry and cloud cover. There are two types of weather files used in this research: the first one used measured weather data for Shanghai during the 2010 and 2011 period, which were used for building model simulation and calibration; the second one was the International Weather for Energy Calculation 2.0 (IWEC2) weather file, which was used for building energy analysis in a typical meteorological year (White Box, 2013).

4.3 The Case-Study Apartment Simulation

4.3.1 The Case-Study Apartment Description

The case-study apartment is in an existing building located in the north-east part of Shanghai, with a longitude of 121.53°E and latitude of 31.28°N. The building was constructed in 1995. As shown in Figure 4.1, it has 26 floors with an underground garage. There are two elevators and staircases for vertical transportation inside the building. Each floor has 8 units and the floor area is 7,861 ft^2. A unit on the 8^{th} floor was identified as the case-study apartment (Figure 4.2) for energy use analysis. The analysis excluded the energy use of the public area such as the corridor lighting and elevator operation energy use. The characteristics of the target apartment are discussed in the next section.

Figure 4.1 The Case-Study Building Street View. The picture shows the northwest view of the case-study building. The building is the only high-rise structure in the neighborhood. Therefore, there is no shading from the nearby buildings.

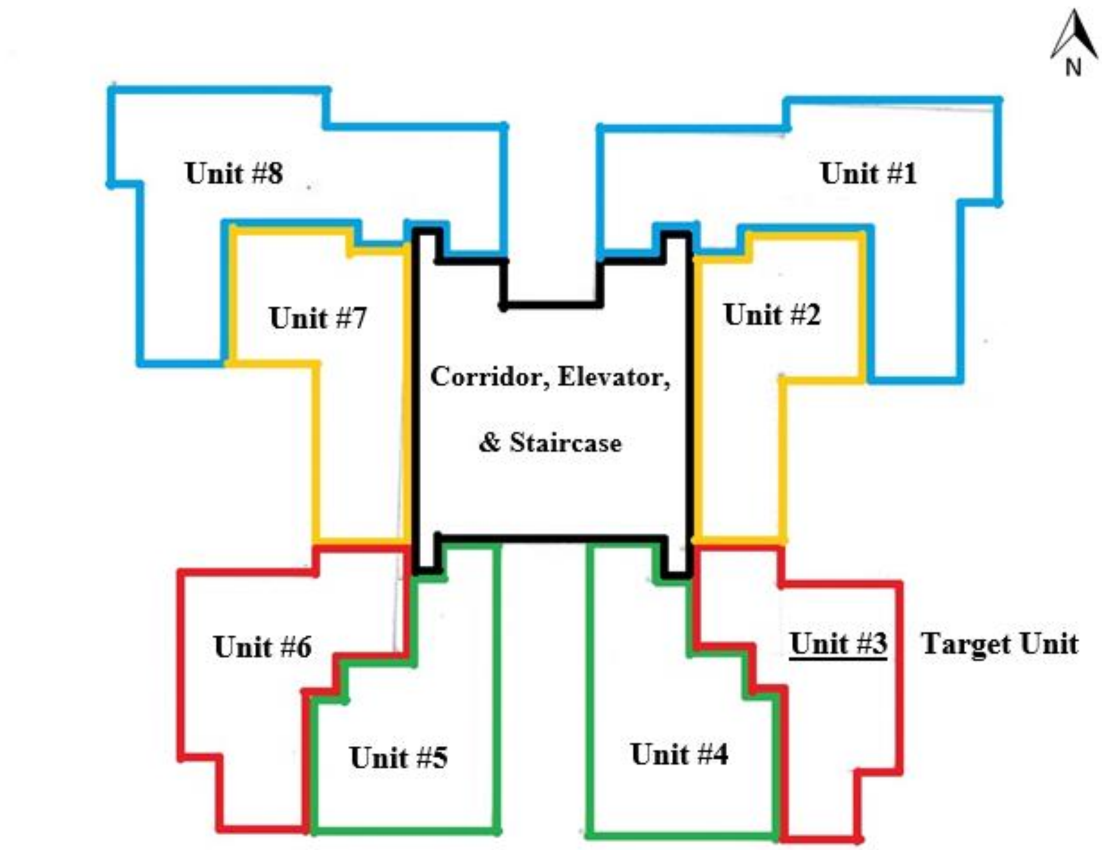


Figure 4.2 The Case-Study Building Floor Plan. There are 8 units on each floor. The layout of the units are symmetric on a north-south central axis. The case-study apartment is located on the south east of the 8th floor.

4.3.2 HVAC Systems

The apartment has packaged air-conditioning systems in each bedroom and the living room. The air conditioning systems are mini-split systems that have air-handling units in the rooms (Figure 4.3) and condensing units on an outside wall (Figure 4.4).

Figure 4.3 Air-Conditioning System Air Handling Unit. This unit is installed in the room. The left bottom shows a portable thermostat that controls the indoor air temperature and supply air flow rate.

Figure 4.4 Air-Conditioning System Condensing Units Installed outside. Each apartment has at least one AC system, some families have one system for each room.

4.3.3 Domestic Hot Water System

There is a natural gas water heater in the apartment (Figure 4.5). The domestic hot water use is mainly for daily showers, and also for dish washing, clothes washing during very cold days in the winter.

Figure 4.5 Natural Gas Water Heater. This is a tankless water heater with manually adjusted water temperature and flow rate.

4.3.4 Case-Study Apartment Energy Use Simulation and Calibration

A computer model of the case-study apartment was created with the eQUEST program. The model included six input categories as shown in Figure 4.6. The input information was determined from architectural drawings, site visits and appliance nameplates. For other information, various assumptions were applied to the simulation model as described below. The detailed model is described as follows:

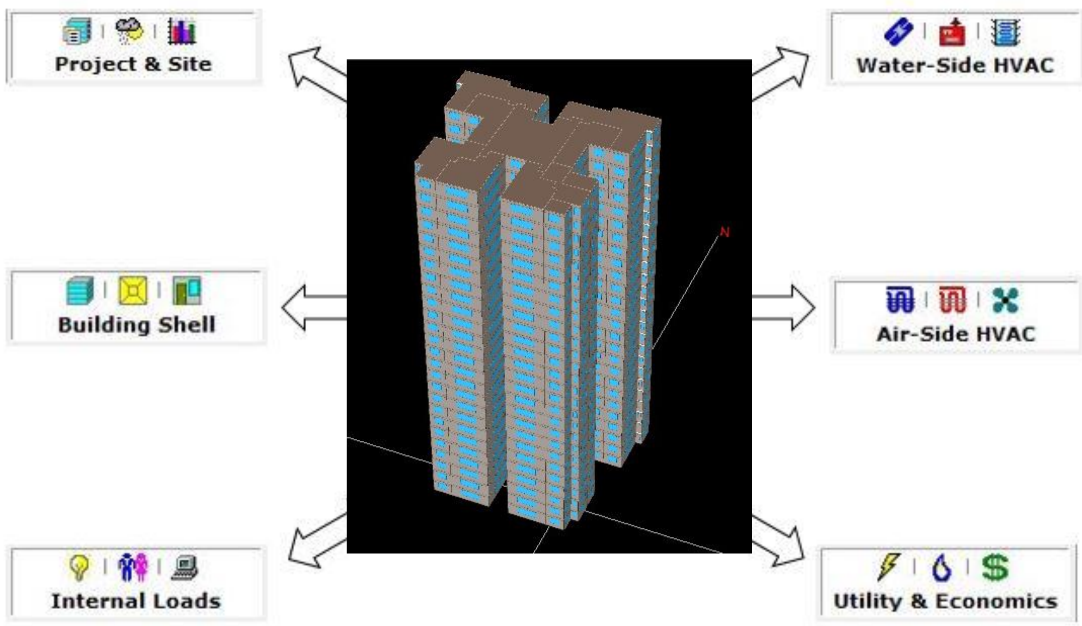


Figure 4.6 Diagram of the eQUEST Model Input Categories. Project & Site category includes overall project information, annual weather data, output report requests; Building & Shell category includes geometry and constructions for building envelope; Internal Loads includes internal loading and schedules for people, lights and equipment; Water-Side HVAC category configures water-side distribution and primary equipment; Air-Side HVAC category configures air-side distribution and secondary equipment; Utility & Economics category assign meters and utility rates.

4.3.4.1 Project and Site

The target building is located in the north-east part of Shanghai. Based on the 2011 lunar calendar, the Chinese holidays were included as follows: New Year's Day (Jan 1st), Spring Festival (Feb 2nd – 4th), Qingming Festival (April 4th), Labor Day (May 1st), Dragon Boat Festival (Jun 6th), Mid-Autumn Festival (Sep 12th), and National Day (Oct 1st – 3rd), these holidays were used in the model.

In addition, although the building is adjacent to a stadium and a three-story nursing school, there was no shadings from nearby buildings. Therefore, the case-study apartment on the 8th floor was not shaded by other buildings.

4.3.4.2 Building Shell

The geometry of the case-study apartment is based on the architectural drawings and on site measurements. The apartment has a master bedroom, a guest bedroom, a bathroom, a living room, a kitchen, and a balcony that is sealed with glazing. A site visit revealed that the bedrooms were closed most of the time. The living room was opened to the bathroom and kitchen through the corridor. Therefore, in the model, the bedrooms were simulated as two separate zones, the living room and the remaining spaces were simulated as one zone because of their similar indoor environments, as shown in Figure 4.7.

The entrance of the apartment is inside the building, and the public corridor is considered as a closed space because the windows in the corridor are closed to the exterior most of the time. The corridor and the adjacent apartments were assumed to have the same indoor air temperature as the case-study apartment, therefore, the walls and floors that were shared by the neighboring apartments and corridor were set as adiabatic.

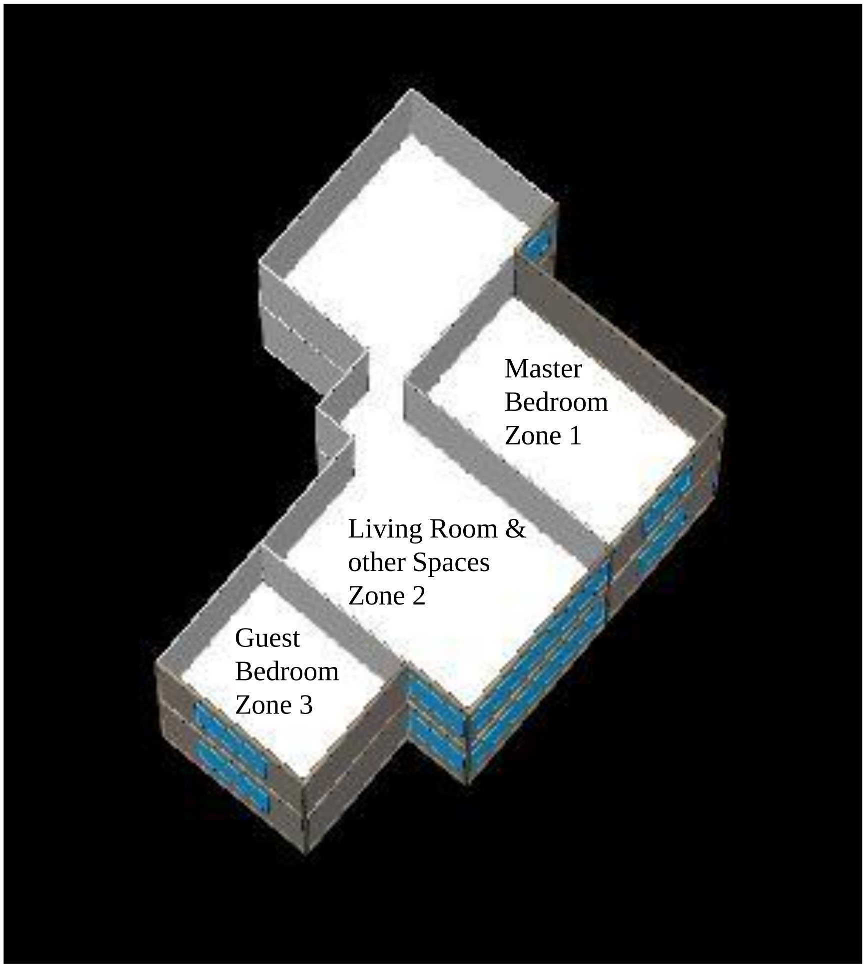


Figure 4.7 The Case-Study Apartment Layout and Zoning.

The building has reinforced concrete structure for exterior walls and floors. The interior walls are common brick. The roof structure is reinforced concrete with insulation and a water-proof covering. All the windows are aluminum-framed, double-pane glass without a thermal break. The entrance door is made of stainless steel. The detail construction for building model were listed in Table 4.2.

Table 4.2 Building Construction Information

Envelope Construction	Layer (from outside to inside)	Material Properties						
		Thickness			Conductivity	Density	Specific Heat	Overall U-Value
		(mm)	(inch)	(ft)	(Btu/hr-ft^2-F)	(lb/ft^3)	(Btu/lb-F)	(Btu/hr-ft^2-F)
Roof	Felt (HF-E3)	20	0.8	0.066	0.1100	70	0.40	0.129
	Roof Insulation (IN74)	50	2.0	0.167	0.0300	16	0.20	
	Concrete Heavy Weight (CC05)	200	7.9	0.667	0.7576	140	0.20	
	Stucco (SC01)	10	0.4	0.033	0.4167	116	0.20	
Exterior Wall	Stucco (SC01)	15	0.6	0.049	0.4167	116	0.20	0.569
	Concrete Heavy Weight (CC05)	200	7.9	0.667	0.7576	140	0.20	
	Stucco (SC01)	10	0.4	0.033	0.4167	116	0.20	
Interior Wall	Stucco (SC01)	10	0.4	0.033	0.4167	116	0.20	0.574
	Common Brick (BK01)	115	4.5	0.377	0.4167	120	0.20	
	Stucco (SC01)	10	0.4	0.033	0.4167	116	0.20	
Interior Floor	Stucco (SC01)	10	0.4	0.033	0.4167	116	0.20	0.431
	Concrete Heavy Weight (CC05)	200	7.9	0.667	0.7576	140	0.20	
	Hard Wood (WD11)	20	0.8	0.063	0.0916	45	0.30	
Ground Floor	Concrete Heavy Weight (CC05)	200	7.9	0.667	0.7576	140	0.20	0.403
	Hard Wood (WD11)	20	0.8	0.063	0.0916	45	0.30	

Window	Glass Properties			
	Gap Thick & Gas Fill	NFRC U-Value (Btu/hr-ft^2-F)	NFRC SHGC	Visible Transmitance
Double Pane Clear Frame w/o Thermal Break (2001)	0.5 inch Air	0.65	0.76	0.81

4.3.4.3 Internal Loads

The occupants of the apartment are a middle-age couple. One of the occupants goes to work on weekdays from 8 am to 5 pm, and the other occupant does housework at home. The couple usually goes out for shopping, visiting friends and entertaining on weekend afternoon.

The apartment has both fluorescent and incandescent lamps for lighting. The main appliances include: a refrigerator, two TVs, a washing machine, a rice cooker, a microwave, an instantaneous water heater, and a personal computer. The detail information are listed in Table 4.3. The schedules for occupants, lighting and appliances are addressed in Figure 4.8, Figure 4.9, and Figure 4.10.

Table 4.3 Lighting and Domestic Appliances Power and Estimated Use Hour

Lighting Location	Power (Watt)	Hour in Use
		Weekdays, Weekends & Holidays
Kitchen	64	7am - 8am
		5pm - 8pm
Bathroom	30	7am - 8am
		8pm - 9pm
Hallway	95	5pm - 9pm
Living room	100	6pm - 9pm
Bedroom	50	9pm - 0am

Appliance	Power (Watt)	Hour in Use	
		Weekdays	Weekends & Holidays
Refrigerator	49	24 hours	24 hours
TV	240	6pm - 9pm	6pm - 9pm
	125	9pm - 0am	9pm - 0am
Cloth washer	300	2pm - 3pm	
Rice cooker	800	5pm - 6pm	5pm - 6pm
Microwave	700	5pm - 6pm	5pm - 6pm
Mini Water heater	800	7am -8 am	8am - 9am
		5pm - 6pm	5pm - 6pm
Personal computer	200	9am - 11am	7pm - 9pm
		1pm - 3pm	
		7pm - 9pm	

This research used ACH method to identify the infiltration rate. The infiltration rate used was assumed to be 0.35 ACH. This value was used in the model. Since the case-study apartment is located on the 8th floor, the stack effect inside the building and wind speed will affect the infiltration rate (Diamond, et al,. 1996). However, this was not simulated in the model.

In the apartment, natural gas was used for cooking. The heat capacity of the gas stove is 4.2 kW (14.33 kBtu/h). The sensible heat gain from cooking was assumed to be 0.63 and latent heat gain to be 0.37 (NatHERS, 2014).

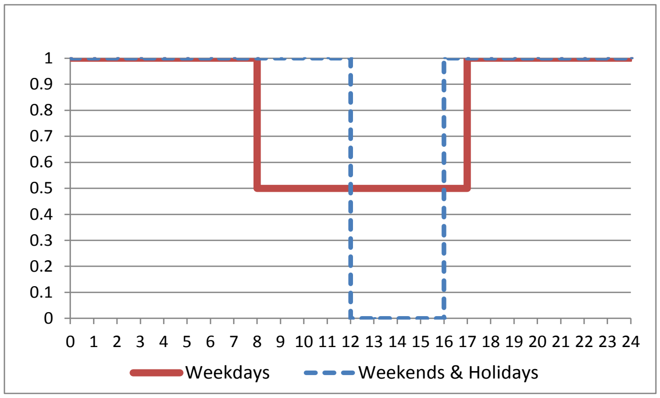


Figure 4.8 Schedule of Occupancy

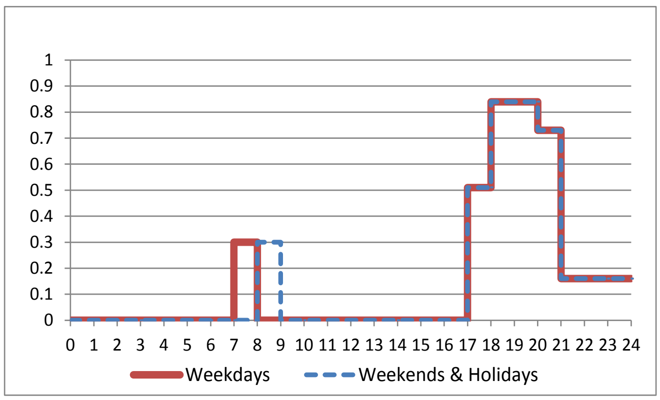


Figure 4.9 Schedule of Lighting

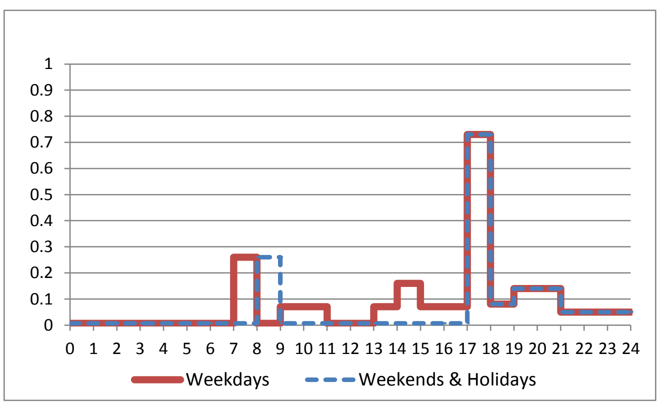


Figure 4.10 Schedule of Appliance

4.3.4.4 *Domestic Hot Water System*

The tankless gas water heater is used mainly for showers. The heat capacity of the water heater is 19.5 kW (66.5 kBtu/h). The maximum supply water flow rate is 2.64 gallon/min. The supply hot water temperature was assumed to be 120 F. The inlet water temperature changes with the season.

4.3.4.5 *HVAC Systems*

The apartment is partially conditioned based on the occupants' requirements. There are three packaged mini-split, air-source heat pump systems for the two bedrooms and the living room. The systems have air-handling units in each room and condensing units outside. The system in the master bedroom has a cooling capacity of 3.5 kW and a heating capacity of 4.2 kW; the system in the guest bedroom has a cooling capacity of 2.5 kW and a heating capacity of 2.9 kW; the system in the living room has a cooling capacity of 3.6 kW and a heating capacity of 4.85 kW. Since the guest bedroom is unoccupied most of the time, this room is set as unconditioned in the model.

4.3.4.6 *Utility Rates*

In Shanghai, residents are encouraged to use electricity at night rather than during the daytime due to a shortage in electricity generation. The electricity rate is ¥0.617/kWh ($0.10/kWh) from 6 am to 10 pm, and ¥0.307/kWh ($0.05/kWh) from 10 pm to 6 am. The natural gas has a uniform rate of ¥2.35/m^3 ($0.38/m^3).

Monthly electric bills from the apartment were used in the model calibration as shown in Table 4.4. The billing dates did not correspond exactly to the calendar month, it started on the 10th day of the current month and ended on the 9th day of the next month. To compare with the bill data, the output of the hourly energy use from the model need to be processed according to the billing period.

Month	Measured (kWh)	Billing Period
Jan	267	12/10/2010 - 1/9/2011
Feb	519	1/10/2011 - 2/9/2011
Mar	250	2/10/2011 - 3/9/2011
Apr	205	3/10/2011 - 4/9/2011
May	131	4/10/2011 - 5/9/2012
Jun	120	5/10/2011 - 6/9/2012
Jul	135	6/10/2011 - 7/9/2012
Aug	209	7/10/2011 - 8/9/2013
Sep	148	8/10/2011 - 9/9/2013
Oct	118	9/10/2011 - 10/9/2013
Nov	109	10/10/2011 - 11/9/2014
Dec	151	11/10/2011 - 12/9/2014

4.3.4.7 As-Built Model Calibration

The case-study apartment model was created with the information from architectural drawings, walk-through visits, and estimations for certain other factors. The main parameters for the as-built model are listed in Table 4.5. The monthly electric bills were used to calibrate the apartment model. The calibration was performed by changing certain parameters in the model to better match the utility bills. The parameters were chosen based on two requirements: (1) the parameter has a significant influence on building energy use; (2) the value of the parameter cannot be determined according to information at hand. Parameters with known nominal values were not tested (e.g., the COP of the A/C system listed on the product nameplate was used in the simulation, assuming that the system remains the same efficiency after several years of use). The parameter that were adjusted during the calibration were as follows: (1) natural ventilation, (2) appliance input power density, (3) thermostat setpoint, (4) window blinds schedule, (5) master bedroom cooling schedule, and (6) living room cooling schedule. In addition, the hot water energy use was also calibrated to match the monthly natural gas bills by adjusting the DHW flow rate.

After adjusting the calibration factors, the simulation data matched with the bill data to an acceptable level. The results of step-by-step calibration will be discussed in the next chapter.

4.4 The Proposed Energy Efficiency Measures to the Case-Study Apartment

By applying an average year weather file to the calibrated model, the typical building energy use was calculated. Therefore, the next step was to identify some measures to improve the energy efficiency of the case-study apartment. By reviewing the literature discussed in Chapter 2.4, and considering all relevant conditions of the case-study apartment, the energy efficiency measures for this study were chosen to be: (1) high-efficiency domestic water heater; (2) high-efficiency refrigerator; (3) exterior wall insulation; (4) windows improvement; (5) high-efficiency lighting; (6) high-efficiency HVAC systems.

Table 4.5 As-Built Model Description

Characteristics	As-Built Model			Information Source
	Living Room	Master Bedroom	Guest Bedroom	
Building				
Building Type	High-rise residential			Architectural drawings
Gross Area (sq.ft)	717			Architectural drawings
Floor to Floor Height (ft.)	9.2			Architectural drawings
Construction				
Exterior Wall Construction (outside - inside)	Stucco - Heavy-weight concrete - Stucco			Architectural drawings
Exterior Wall Insulation (hr-sq.ft-F/Btu)	N/A			
Interior Wall Construction (outside - inside)	Stucco - Brick - Stucco			Architectural drawings
Interior Floor Construction (outside - inside)	Stucco - Heavy-weight concrete - Hard wood			Architectural drawings
U-Factor of Glazing (Btu/hr-sq.ft-F)	0.65			NFRC
Solar Heat Gain Coefficient (SHGC)	0.76			NFRC
Space Conditions				
Number of People	2			Site visit
Infiltration Rate (ACH)	0.35			ASHRAE 62-1989
Lighting Power Density (W/sq.ft)	0.43			Site visit and estimation
Equipment Power Density (W/sq.ft)	4.45			Site visit and estimation
Conditioning Situation	Conditioned	Conditioned	Unconditioned	Site visit
Space Heating Setpoint (F)	63	63		5-P model
Space Cooling Setpoint (F)	79	79		5-P model
HVAC System				
System Type	Air-source heat pump			Product nameplate and calculation
Cooling Capacity (Btu/hr)	12,000	12,000	8,400	
SEER	10	12	10	
Heating Capacity (Btu/hr)	-16,550	14,330	-9,890	
HSPF	10	11	12	
Ventilation (cfm)	0	0	0	
Supply Air Flow (cfm)	318	240	240	
DHW System				
Heat Source	Natural Gas			Product nameplate and manual
Heat Capacity (kBtu/hr)	66.5			
Energy Factor	0.62			
Outlet Temperature Setpoint (F)	120			Estimation
Inlet Temperature Setpoint (F)	Ground Temperature			Weather file

4.4.1 High-Efficiency Domestic Water Heater

The existing natural gas water heater has the energy factor of 0.62, which is low compared to newer water heaters. Therefore, a heat pump water heater (HPWH) was chosen as a more efficient DWH. The refrigeration cycle enables the HPWH to be much more efficient than an electric resistance or natural gas water (Energy Star, 2013).

4.4.2 High-Efficiency Refrigerator

The refrigerator in the apartment also consumes a large amount of household energy. The current refrigerator uses 1.17 kWh/day, while, newer, more energy efficient refrigerators of the same size in the market have a much lower energy use of 0.5 kWh/day or less. Therefore, a new refrigerator was chosen to compare with the existing refrigerator.

4.4.3 Exterior Wall Insulation

Thermal insulation is an important strategy to reduce building energy use. Thermal insulation can be installed on either external side or internal side of the exterior wall. Each method has advantages. External thermal insulation (ETI) can prevent moisture condensation, stops thermal bridging of the envelope and can utilize the building thermal mass to dampen the interior temperature swing. Internal thermal insulation (ITI) is also an option. However, it is more disruptive to install, although it costs less to insulate and preserves the façade of buildings (Kolaitis et al., 2013). In regards to energy savings, the performance of ETI has been proven to be better than ITI (Kossecka and Kosny, 2002) . Therefore, the case-study building has no insulation with the exterior wall, it may be more feasible to apply ETI, which would be less disruptive to the normal life of the residents.

4.4.4 Windows Improvement

Previous studies have shown that a large amount of the heat loss in a building can be attributed to the glazing. The energy performance of a window depends on its thermal transmittance (U-value), solar heat gain coefficient (SHGC), and the air leakage due to the frame and installation airtightness (Gasparella, 2011). Unfortunately, improving a window's U-value and SHGC can have the opposite effect on heating and cooling performance. A building's heating demand is reduced with a lower U-value and a higher SHGC value. However, cooling demand is reduced with a lower SHGC value (Grynning, 2013). Based on the climate of Shanghai, the building has both heating and cooling demand, so two types of glazing were tested to compare the energy use. The first type of window has a lower U-value from the use of a thermal break in the frame while the SHGC remains the same. The second type of window is to further reduce the SHGC value and make it an ASHRAE Standard 90.1code compliant window.

4.4.5 High-Efficiency Lighting

The lighting for the base-case apartment is from incandescent lamps. Incandescent lamps are very inefficient as a lighting source, and have a short lifespan. Therefore, LED lamps will be a substitute as a high efficiency lamp with a longer life.

4.4.6 High-Efficiency HVAC System

According to the survey by Hu et al., (2013), the energy use for space heating and cooling occupied 15% of the total end use energy for a typical residence in 2006. Since the current HVAC system has been used for more than 7 years, the system is less efficient than newer systems. Therefore, a more energy efficient system will be tested to compare with the current one for the energy performance.

4.5 Economic Analysis

An economic analysis of the case-study apartment was performed using a simple payback method to evaluate the EEMs. Simple payback considers the initial investment costs from EEMs and the resulting annual energy cost savings. The payback period is the amount of time to recover the initial cost through the reduction in energy cost each year. In this study, the simple payback was calculated in respect of individual and combined EEMs applied to the case-study apartment. By analyzing the initial cost, energy cost savings and estimated simple payback time, the feasibility of individual and combined EEMs was addressed.

4.6 Summary of Methodology

This chapter described the research methods that were used to develop a simulation of the case-study apartment, a list of energy-efficiency measures and economic analysis for their feasibility.

First, the weather condition in Shanghai was analyzed based on ASHRAE Standard 90.1-2004 climate classification method. Shanghai was identified to be in the Warm-Humid (3A) climate zone. Therefore, new buildings in Shanghai should comply with the energy codes for this zone if they subscribe to the ASHRAER Standard 90.1.

The case-study apartment is located on the 8th floor of an existing building. The characteristics of the building and the apartment were identified based on the architectural drawings, walk-through visits and appliance nameplates. An eQUEST model was created to simulate the case-study apartment in respect of building geometry and construction, internal loads, HVAC system and DWH system. Twelve months of utility bills were used to calibrate the case-study apartment energy model.

Once the model was calibrated, several measures were identified to improve the energy efficiency of the case-study apartment, including: a high-efficiency domestic water heater, a high-efficiency refrigerator, exterior wall insulation, window improvement, high-efficiency lighting and high-efficiency HVAC systems.

Finally, an economic analysis was conducted to check the feasibility of individual and combined energy-efficiency measures.

5 ANALYSIS AND RESULTS

5.1 As-Built Model Calibration

5.1.1 Energy Use Regression Model

The Inverse Model Toolkit (IMT) (Kissock et al., 2004) was used to create a regression model to represent the actual apartment energy performance under different weather conditions. According to the electric bills, the apartment had much higher energy use in February. A discussion with the apartment occupants revealed that the Chinese Spring Festival was in that month and it was a one week holiday. With several family parties held in that week, it was reasonable to have energy use for that month much higher than the rest of the months.

The utility energy use data was then processed with a 5-parameter regression model to represent the apartment energy performance with respect to outdoor air temperature, The coefficients of the model are listed in the Appendix D. As shown in Figure 5.1, the utility data was well matched with the model except the February data, which was therefore excluded from further analysis. Based on the model, the non-weather dependent energy use was 5.4 Wh/day-ft^2. There were heating loads when the outdoor air temperature below 63°F, and cooling loads when the outdoor air temperature above 79°F. Therefore, these temperatures were used as the thermostat setpoints for simulation test. The comparison between the utility data and 5-parameter model were shown in Table 5.1.

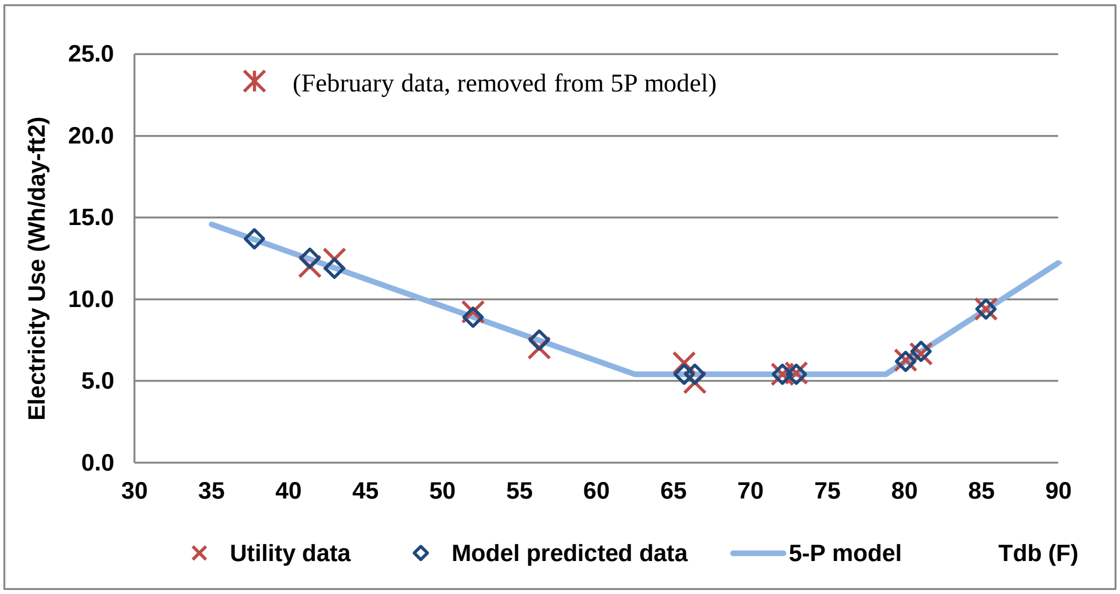


Figure 5.1 Utility Data Vs. 5-P Model. The utility data is monthly data, they were converted into daily average data, which then eliminated the effect of different days in each month, and this increase the accuracy of the model.

Table 5.1 Utility Data Vs. Model predicted Data

Month	Outdoor Air Temperature (°F)	Utility Data (Wh/day-ft^2)	Model Predicted Data (Wh/day-ft^2)
Jan	41.4	12.0	12.5
Feb	37.8	23.3 (Removed)	13.7
Mar	43.0	12.5	11.9
Apr	52.0	9.2	8.9
May	65.7	6.1	5.4
Jun	72.1	5.4	5.4
Jul	80.1	6.3	6.2
Aug	85.3	9.4	9.4
Sep	81.1	6.7	6.8
Oct	73.0	5.5	5.4
Nov	66.4	4.9	5.4
Dec	56.3	7.0	7.5

5.1.2 As-Built Model Calibration

After an initial model was created that captured the basic building geometry, equipment and interior conditions, an as-built simulation model was then calibrated until it reached an acceptable goodness-of-fit as described in Chapter 2.8. The calibration was performed by changing certain parameters in the model as described. After rerunning the simulation, the results from the building energy performance report were then extracted and compared to the measured utility bills. Table 5.2 shows the calibration factors that were used for each run, including: (1) Natural ventilation, (2) Appliance input power density, (3) Thermostat setpoint, (4) Window blinds schedule, (5) Master bedroom cooling schedule, (6) Living room cooling schedule, (7) Readjusting appliance input power density. In the following sections, the calibration factors are described with calibration results for each run.

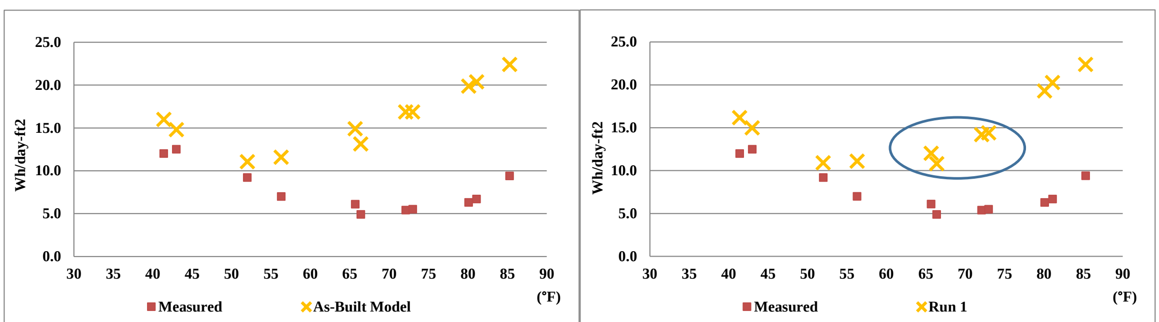
Table 5.2 Calibration Factors for Each Run

Calibration Factors		As-built Model	Run 1	Run 2	Run 3	Run 4	Run 5	Run 6	Run 7
1	Natural Ventilation	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2	Appliance Input Power Density (W/ft^2)	4.45	4.45	2	2	2	2	2	1.7
3	Thermostat Setpoint (F)	Heating: 63 Cooling: 79	Heating: 63 Cooling: 79	Heating: 63 Cooling: 79	Heating: 66 Cooling: 82.5	Heating: 66 Cooling: 82.5	Heating: 66 Cooling: 82.5	Heating: 66 Cooling: 82.5	Heating: 66 Cooling: 82.5
4	Blinds Schedule	No	No	No	No	Yes	Yes	Yes	Yes
5	Master Bedroom Cooling Schedule	No	No	No	No	No	Yes	Yes	Yes
6	Living Room Cooling Schedule	No	No	No	No	No	No	Yes	Yes

5.1.2.1 Natural Ventilation

The as-built model always uses air-conditioning for cooling. However, the fact is that the residents prefer opening the windows and having natural ventilation for cooling when the outdoor air is relatively cool and dry. Once the residents feel the room is overcooled, they usually close the windows. Therefore, in this calibration run, the windows of the model were simulated as “open” when natural ventilation can provide enough cooling to keep the zone temperature within or below the throttling range of the cooling thermostat setpoint (79°F); alternatively, the windows were then closed once the room air temperature fell below 68°F, which prevented the room from being overcooled and then having heating loads.

After the first run, the monthly electricity use in May, June, October and November (circled in the Figure 5.2) decreased by about 15%, and the rest of the months had no changes. This is within expectation, because the outdoor air temperature in the four months falls between 68°F and 79°F most of the time, thus the room gets natural cooling through ventilation instead of mechanical cooling.

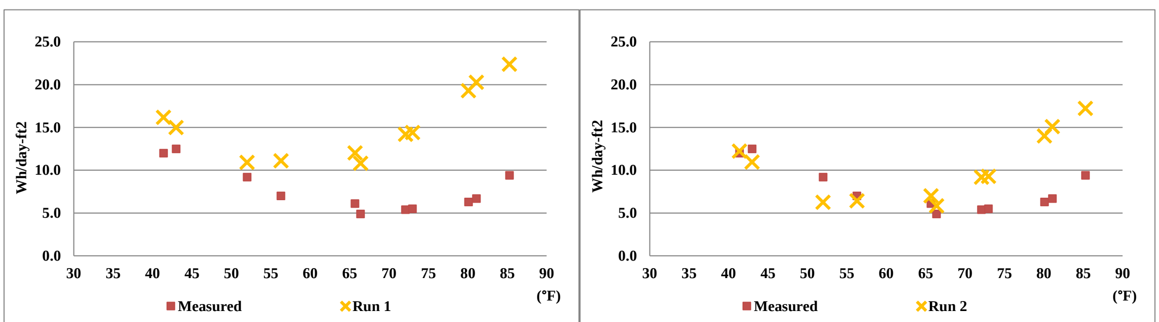


Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
As-Built Model	16	14.8	11.0	14.9	16.9	19.9	22.4	20.4	16.9	13.1	11.6
Run 1	16.2	15.0	10.9	12.0	14.2	19.3	22.4	20.3	14.4	10.8	11.1

Figure 5.2 Monthly Energy Use Before and After Calibration Run 1

5.1.2.2 Appliance Power Density

According to the 5-parameter model of the utility billing data, the apartment had the lowest energy use in November. Therefore, it was assumed there was no cooling or heating loads in this month, and all the electric loads were from the lighting and domestic appliances. Therefore, the objective of this calibration step was to match the simulated energy use with the billing data in November. In the second run, the appliance input power density was changed from 4.45 W/ft^2 to 2.0 W/ft^2. As shown in Figure 5.3, the simulated data moved closer to the billing data for November as well as the other months. The annual simulated energy use was therefore reduced by 30%. The lighting and appliance electricity loads were very important to the calibration process, because the heat gain from them had a great impact on both heating and cooling loads.

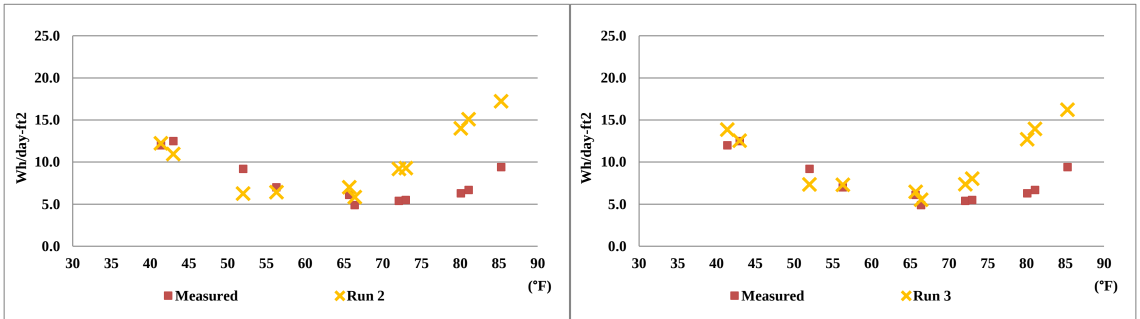


Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 1	16.2	15	10.9	12	14.2	19.3	22.4	20.3	14.4	10.8	11.1
Run 2	12.2	11.0	6.3	7.0	9.2	14.0	17.2	15.1	9.3	5.8	6.4

Figure 5.3 Monthly Energy Use Before and After Calibration Run 2

5.1.2.3 Thermostat Setpoint

According to the results from the 5-parameter model, the apartment thermostat setpoint was originally set at 63°F for heating and 79°F for cooling. Therefore, the objective of this calibration step was to change the thermostat setpoint for both heating and cooling until there are no heating or cooling loads in November, which was mentioned in previous section, since November was assumed to only have electricity loads from lighting and appliances. After several additional tests, the heating thermostat setpoint was set at 66°F with the lowest CV(RMSE). In contrast, the cooling thermostat setpoint was set at 82.5°F to better match that month that had no cooling while maintain the lowest CV(RMSE). It was observed that 66°F seemed relatively low for heating. However, this low setpoint is reasonable considering the lifestyle of the apartment occupants in Shanghai. As discussed in Section 2.6, residents in Shanghai have very low heating energy use compared to the U.S. One reason for this is because the people in Shanghai prefer to wear more clothing indoors in the winter rather than pay a lot of money for space heating. So 66°F was considered to be an acceptable thermostat setpoint for the residents. After the adjustment, the annual heating loads increased and cooling loads decreased as shown in Figure 5.4, which further reduced the difference between the model and measured data.



Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 2	12.2	11.0	6.3	7.0	9.2	14.0	17.2	15.1	9.3	5.8	6.4
Run 3	13.9	12.5	7.3	6.5	7.4	12.7	16.2	13.9	8.0	5.5	7.3

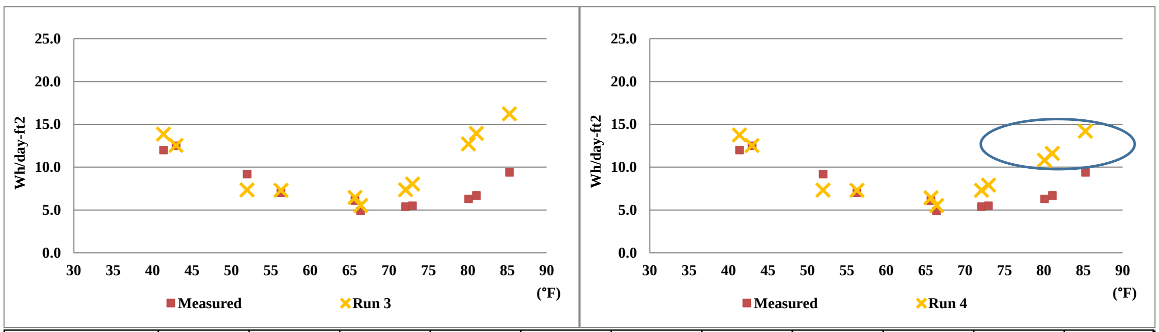
Figure 5.4 Monthly Energy Use Before and After Calibration Run 3

5.1.2.4 Window Blinds Schedule

Window blinds affect solar heat gain through the windows. Based on the information from the residents, the blinds in the bedroom were closed at night and opened in the morning. For the living room, there are large windows facing east. In the summer, the windows in the living room are shaded by the blinds most of the time; at night, the blinds were opened when the occupants open the windows for ventilation. The blinds also impacted heat conduction through the windows. Therefore, a multiplier of 0.5 was applied to the overall glass conductance in the model to estimate the impact of the blinds. The outcome of the simulation showed that the use of the blinds in this way reduced the cooling loads in the summer by 13% to 17% (circled in Figure 5.5).

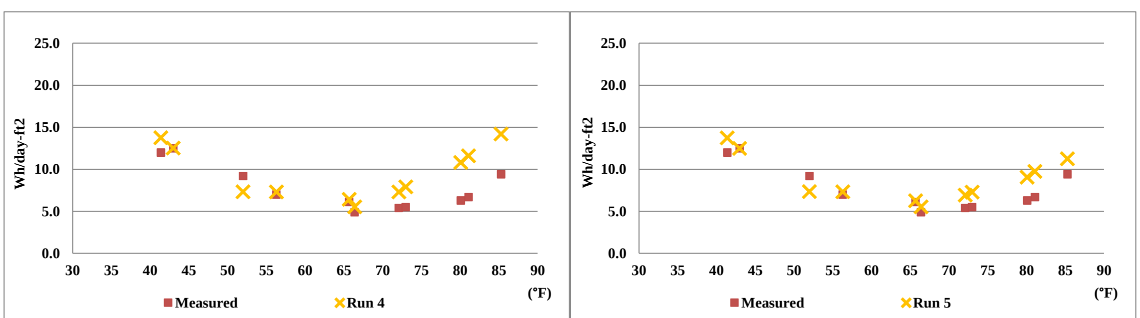
5.1.2.5 Master Bedroom Cooling Schedule

The measured energy use for cooling in the summer is quite low compared to the simulation. Based on information from the residents, they preferred to use an electric fan for cooling most of the time. In the summer, the air conditioning system will work at most for two hours when residents go to bed. After that, an electric fan is used for air circulation throughout the night. Therefore, in the model, the system was set to operate for two hours in the master bedroom, which further decreased the cooling energy use as shown in Figure 5.6.



Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 3	13.9	12.5	7.3	6.5	7.4	12.7	16.2	13.9	8.0	5.5	7.3
Run 4	13.8	12.5	7.3	6.4	7.3	10.8	14.2	11.6	7.9	5.5	7.3

Figure 5.5 Monthly Energy Use Before and After Calibration Run 4

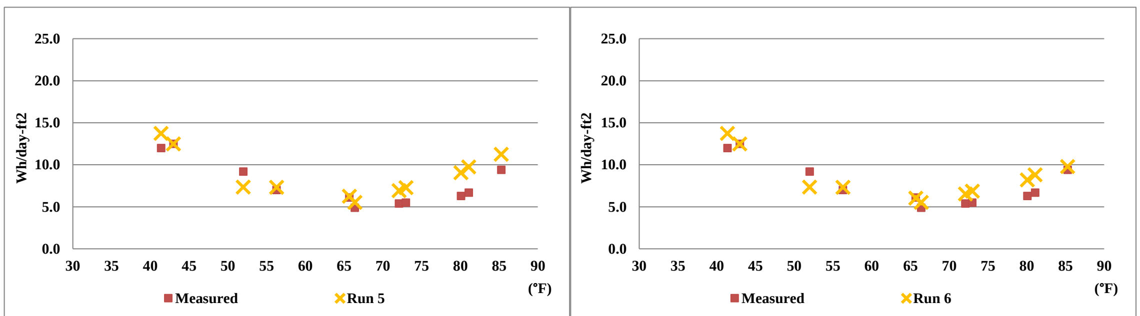


Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 4	13.8	12.5	7.3	6.4	7.3	10.8	14.2	11.6	7.9	5.5	7.3
Run 5	13.7	12.5	7.3	6.3	6.9	9.1	11.3	9.7	7.3	5.5	7.3

Figure 5.6 Monthly Energy Use Before and After Calibration Run 5

5.1.2.6 Living Room Cooling Schedule

In addition to the reduced operation schedule for the bedroom, an interview with the residents determined that on summer weekdays, when one of the residents went to work, the other would prefer to have the fan for cooling instead of the air conditioning. Therefore, the air conditioning was only used when both people were at home. By shutting off the air conditioning in certain period, it can be seen from Figure 5.7 that the cooling energy use was further reduced.

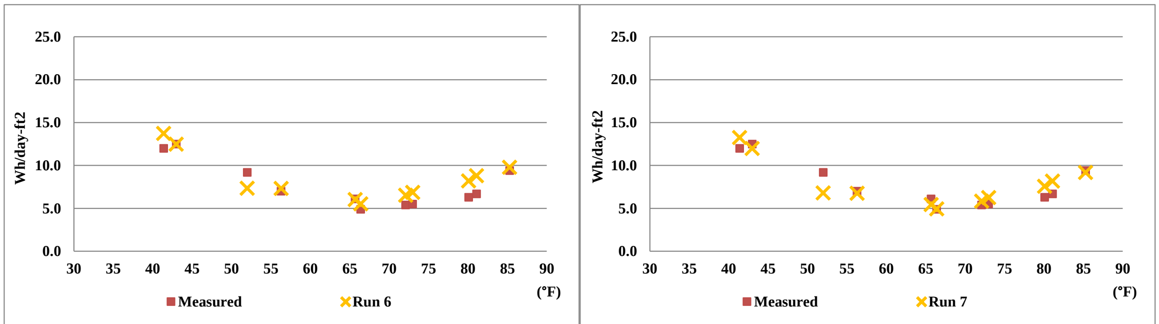


Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 5	13.7	12.5	7.3	6.3	6.9	9.1	11.3	9.7	7.3	5.5	7.3
Run 6	13.7	12.5	7.3	6.0	6.5	8.2	9.8	8.8	6.9	5.5	7.3

Figure 5.7 Monthly Energy Use Before and After Calibration Run 6

5.1.2.7 Appliance Power Density

Finally, to make the model more closely match with the utility billing data, the appliance power density was readjusted. When the appliance power density was reduced from 2.0 W/ft^2 to 1.7 W/ft^2, the simulated daily electricity use in November was close to the measured data as shown in Figure 5.8. The CV(RMSE) between the simulated data and real data was 14.7% and NMBE was -1.7%. Based on ASHRAE Guideline 14-2002, the model was reasonably well calibrated.



Run #	Jan	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
$T_{outdoor}$	41.4	43.0	52	65.7	72.1	80.1	85.3	81.1	73.0	66.4	56.3
Run 6	13.7	12.5	7.3	6.0	6.5	8.2	9.8	8.8	6.9	5.5	7.3
Run 7	13.3	12.0	6.8	5.4	5.8	7.6	9.2	8.2	6.3	4.9	6.8

Figure 5.8 Monthly Energy Use Before and After Calibration Run 7

5.1.2.8 Overview of Electricity Calibration

The model calibration included seven steps, Table 5.3 listed the objective of each step, and the goodness-of-fit values for calibration including CV(RMSE) and NMBE. Table 5.4 listed the main parameters for the calibrated model, the red font represented the new value of the parameter after the calibration.

Table 5.3 Summary of Calibration Process

Step #	Calibration Factor	Value	CV(RMSE)	NMBE	Calibration Objective
0	As-Built Model	As-built model description	129.0	-120.3	
1	Natural Ventilation	Free cooling by natural ventilation Close the window when T_{room} below 68F	115.4	-105.8	Reduce the cooling energy use in Spring and Fall
2	Appliance Power Density	From 4.45W/ft^2 to 2.0 W/ft^2	62.7	-37.1	Reduce the baseline energy according to November data
3	Thermostat Setpoint	Heating: from 63F to 66F Cooling: from 79F to 82.5F	51.6	-34.2	No heating/cooling loads in November
4	Blinds Schedule	Bedroom: blinds off at night Living room: blinds off at daytime during summer	37.7	-25.6	Reduce cooling energy use in Summer
5	Master Bedroom Cooling Schedule	Cooling off after 2 hours conditioning	23.6	-15.6	
6	Living Room Cooling Schedule	No daytime cooling for weekdays	17.7	-10.0	
7	Appliance Power Density	From 2.0W/ft^2 to 1.7 W/ft^2	14.7	-1.7	Simulation data match with measured data in November

5.1.2.9 Natural Gas Use Simulation and Calibration

Natural gas was used for cooking and domestic hot water in the case-study apartment. The cooking energy use was stable according to the fixed daily cooking schedule. The hot water energy use was simulated according to the existing water heater properties. The inlet water temperature for the analysis used the monthly average ground temperatures. The outlet water temperature was assumed to be maintain at 120 F. The monthly natural gas bill was used to do calibration. By adjusting the hot water flow rate into 1.32 gallon/min, the simulated natural gas use matched with the utility bills to an acceptable level, as CV(RMSE) of 11.68% and NMBE of -1.57%. The calibrated data and measured data from utility bills are shown in Figure 5.9 and Table 5.5.

Table 5.4 Calibrated Model Description.

Characteristics	As-Built Model			Information Source
	Living Room	Master Bedroom	Guest Bedroom	
Building				
Building Type	High-rise residential			Architectural drawings
Gross Area (sq.ft)	717			Architectural drawings
Floor to Floor Height (ft.)	9.2			Architectural drawings
Construction				
Exterior Wall Construction (outside - inside)	Stucco - Heavy-weight concrete - Stucco			Architectural drawings
Exterior Wall Insulation (hr-sq.ft-F/Btu)	N/A			
Interior Wall Construction (outside - inside)	Stucco - Brick - Stucco			Architectural drawings
Interior Floor Construction (outside - inside)	Stucco - Heavy-weight concrete - Hard wood			Architectural drawings
U-Factor of Glazing (Btu/hr-sq.ft-F)	0.65			NFRC
Solar Heat Gain Coefficient (SHGC)	0.76			NFRC
Space Conditions				
Number of People	2			Site visit
Infiltration Rate (ACH)	0.35			ASHRAE 62-1989
Lighting Power Density (W/sq.ft)	0.43			Site visit and estimation
Equipment Power Density (W/sq.ft)	**1.7**			Calibration
Conditioning Situation	Conditioned	Conditioned	Unconditioned	Site visit
Space Heating Setpoint (F)	**66**	**66**		Calibration
Space Cooling Setpoint (F)	**82.5**	**82.5**		Calibration
HVAC System				
System Type	Air-source heat pump			Product nameplate and calculation
Cooling Capacity (Btu/hr)	12,000	12,000	8,400	
SEER	10	12	10	
Heating Capacity (Btu/hr)	-16,550	14,330	-9,890	
HSPF	10	11	12	
Ventilation (cfm)	0	0	0	
Supply Air Flow (cfm)	318	240	240	
DHW System				
Heat Source	Natural Gas			Product nameplate and manual
Heat Capacity (kBtu/hr)	66.5			
Energy Factor	0.62			
Outlet Temperature Setpoint (F)	120			Estimation
Inlet Temperature Setpoint (F)	Ground Temperature			Weather file

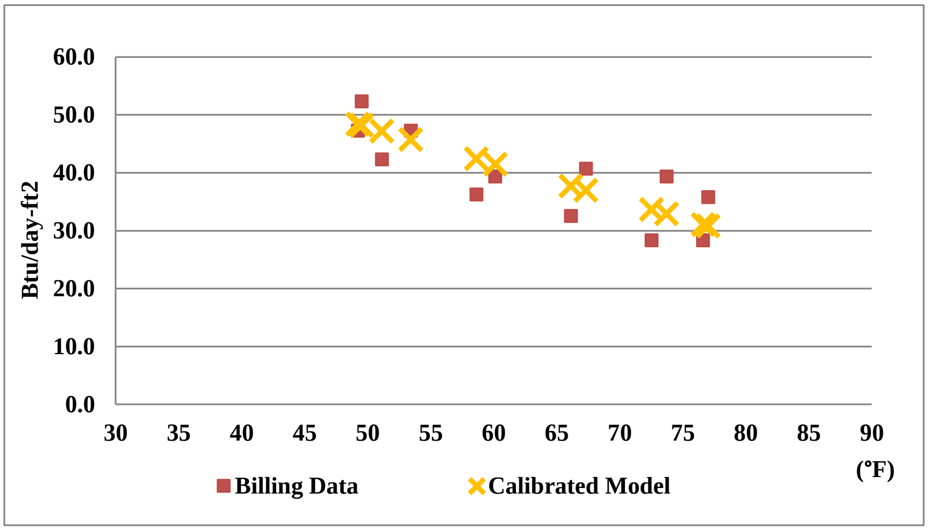


Figure 5.9 Natural Gas Use: Measured Vs. Calibrated.

Table 5.5 Natural Gas Use from the Utility Bills and Model

Month	Ground Temp (°F)	Billed Data		Calibrated Model	
		(m^3/Month)	(Btu/day-ft^2)	(m^3/Month)	(Btu/day-ft^2)
Jan	53.4	30.0	47.2	29.0	45.7
Feb	49.5	30.0	52.3	27.6	48.2
Mar	49.2	30.0	47.2	30.7	48.4
Apr	51.1	26.0	42.3	29.0	47.2
May	58.6	23.0	36.2	26.9	42.4
Jun	66.1	20.0	32.5	23.2	37.7
Jul	72.5	18.0	28.3	21.4	33.7
Aug	76.6	18.0	28.3	19.7	31.1
Sep	77.0	22.0	35.8	18.9	30.8
Oct	73.7	25.0	39.4	20.9	32.9
Nov	67.3	25.0	40.7	22.7	37.0
Dec	60.1	25.0	39.4	26.4	41.5

5.2 Whole-Building Energy Use Analysis

After the model was calibrated with the coincident weather data, an IWEC2 weather file was then used to simulate the energy use in a typical meteorological year. As Figure 5.10 shows, the energy use for lighting and electrical appliances was constant throughout the year. There were more heating loads in winter than cooling loads in summer based on the residents' lifestyle. The simulated natural gas use is shown in Figure 5.11. The cooking energy use was relatively constant, while the domestic hot water use consumed more energy in winter than in summer, which was due to the colder inlet water temperatures (i.e. ground tempertures) in the winter (Appendix C), since the usage (i.e., gallon per day) were assumed to be constant throughout the year. The hot water energy use was higher in March and April than the rest of the months, this came from the lowest ground temperatures in these two months. February also had very low ground temperatures, however, since it only has 28 days, the energy use was not has high as March and April.

Since the purpose of this research was to analyze the annual end-use energy consumption and apply energy efficiency measures to help reducing energy use and save energy costs, it is important to consider both in any analysis. Based on the results of the simulation (Figure 5.12), the domestic water heating was the largest energy use, appliance ranked the second, and cooking was the third. Space cooling used the least energy because of the residents' lifestyle. Although people use less electricity than natural gas, unfortunately, they pay more for electricity than natural gas (Figure 5.13). Therefore, in any economic analysis, the cost of the energy source plays an important role

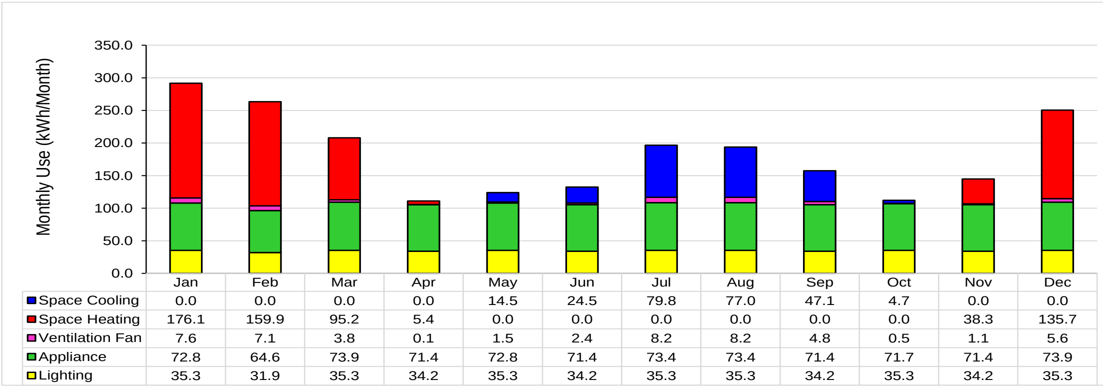


Figure 5.10 Monthly Electricity Consumption

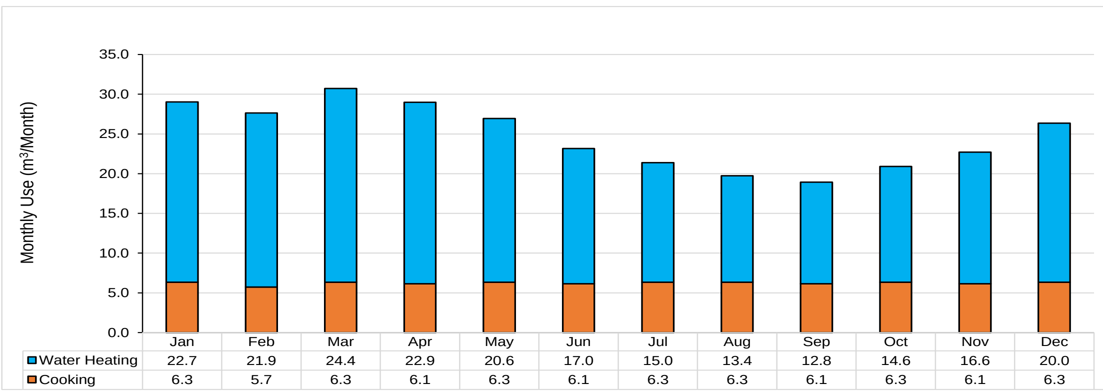


Figure 5.11 Monthly Natural Gas Consumption

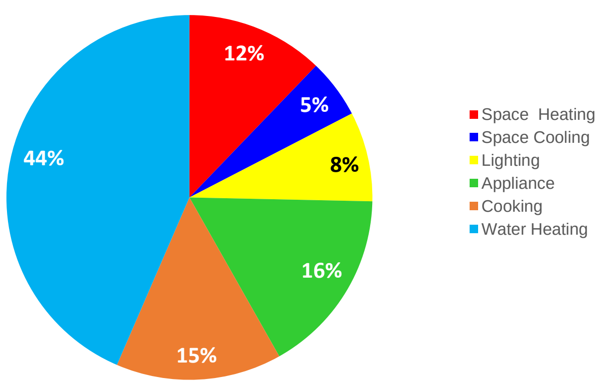


Figure 5.12 Case-Study Apartment Annual Energy End Use

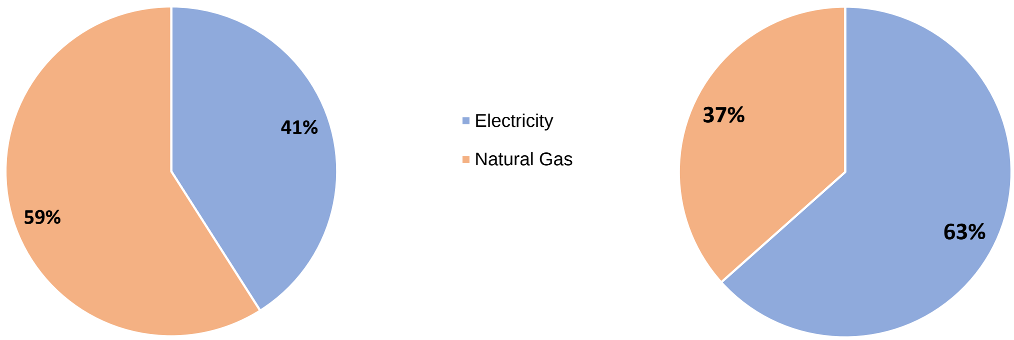
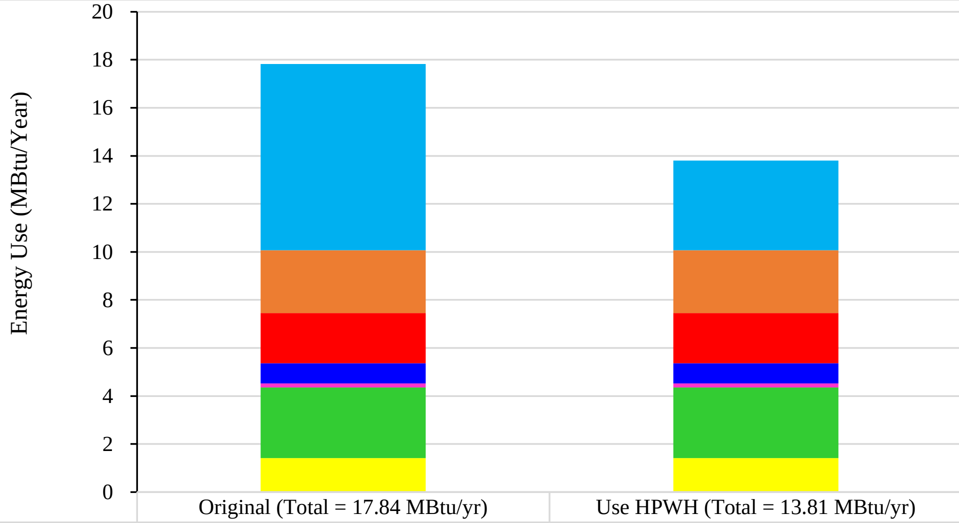


Figure 5.13 The Energy Use (left) and Energy Cost (right) Comparisons between Electricity and Natural Gas

5.3 Energy Efficiency Measures Analysis

5.3.1 High Efficiency Domestic Water Heater

For this energy efficiency measure, an electric heat pump water heater (HPWH) was substituted to the existing natural gas water heater. The HPWH has a 50-gallon storage tank with an electric resistance back up heat source. The HPWH has an energy factor (EF) of 2.4, which is much higher than the EF of 0.62 of the existing water heater. As Figure 5.14 shows, the HPWH reduced the energy use for domestic water heating by 51.9% from 7.76 MBtu/yr to 3.73 MBtu/yr. This decreased the total electricity use by 22.6 % from 17.84 MBtu/yr to 13.81 MBtu/yr. Compared to a tankless natural gas water heater, a heat pump water heater with a storage tank saves a significant of energy use.

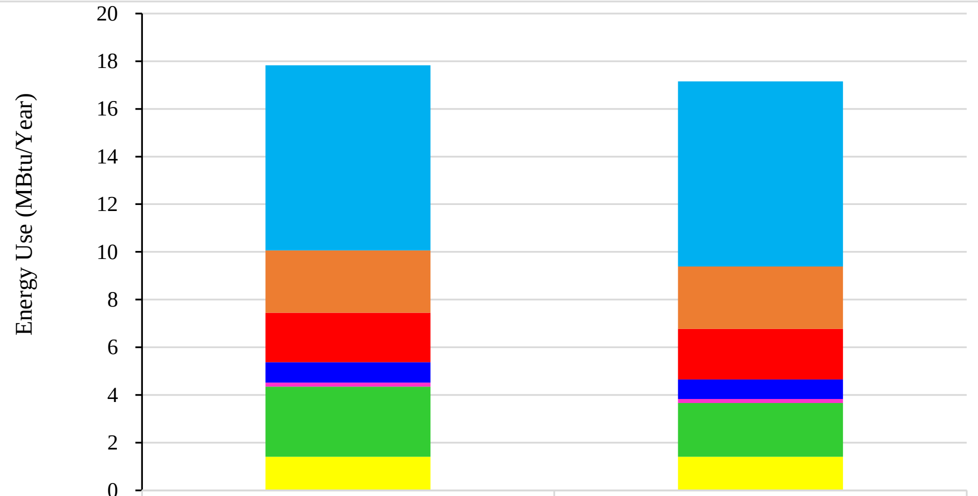


	Original (Total = 17.84 MBtu/yr)	Use HPWH (Total = 13.81 MBtu/yr)
Water Heating	7.76	3.73
Cooking	2.61	2.61
Space Heating	2.08	2.08
Space Cooling	0.84	0.84
Ventilation Fan	0.17	0.17
Appliance	2.94	2.94
Lighting	1.42	1.42

Figure 5.14 Comparison of the Annual Energy Use of the Base Case Water Heater and the Retrofit with a HPWH

5.3.2 High Efficiency Refrigerator

The next energy efficiency measure evaluated was a high efficiency refrigerator. The existing refrigerator has a volume of 6.5 ft^3 and a rated daily energy use of 1.17 kWh/day. In this energy efficiency strategy, the refrigerator was replaced by one with the same volume but a much lower daily energy use of 0.49 kWh/day. Figure 5.15 shows that the energy use for domestic appliances reduced by 23.5% from 2.94 MBtu/yr to 2.25 MBtu/yr. The total annual use was reduced by 3.8% from 17.84 MBtu/yr to 17.16 MBtu/yr. Because of the increased efficiency of the refrigerator, the heat rejected to the kitchen was also reduced. Therefore, there was slightly increase for space heating energy use and decrease for space cooling energy use as expected.



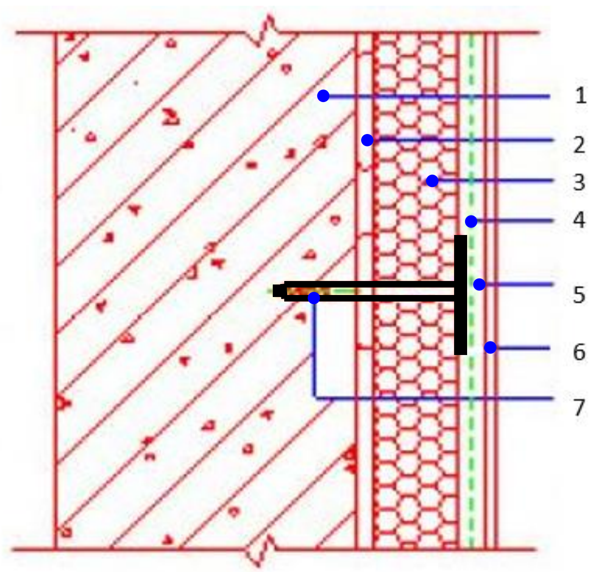
	Original (Total = 17.84 MBtu/yr)	New Refrigerator (Total = 17.16 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	2.12
Space Cooling	0.84	0.82
Ventilation Fan	0.17	0.17
Appliance	2.94	2.25
Lighting	1.42	1.42

Figure 5.15 Comparison of the Annual Energy Use of the Base Case Refrigerator and the Retrofit with High-Efficiency Refrigerator

5.3.3 Insulation Application

In this energy efficiency measure, external thermal insulation (ETI) was applied to the exterior wall of the case-study building. Based on the China industry standard - “Technical Specification for External Thermal Insulation on Walls” (JGJ 144-2004, 2005), the external thermal insulation system is illustrated as Figure 5.16, a 58mm-thick Expanded Polystyrene (EPS) board was chosen as the insulation material. The thickness of the insulation layer was determined by referring to ASHRAE Standard 90.1-2013 (ASHRAE, 2013): under Climate Zone 3A, minimum continuous insulation of R-9.5

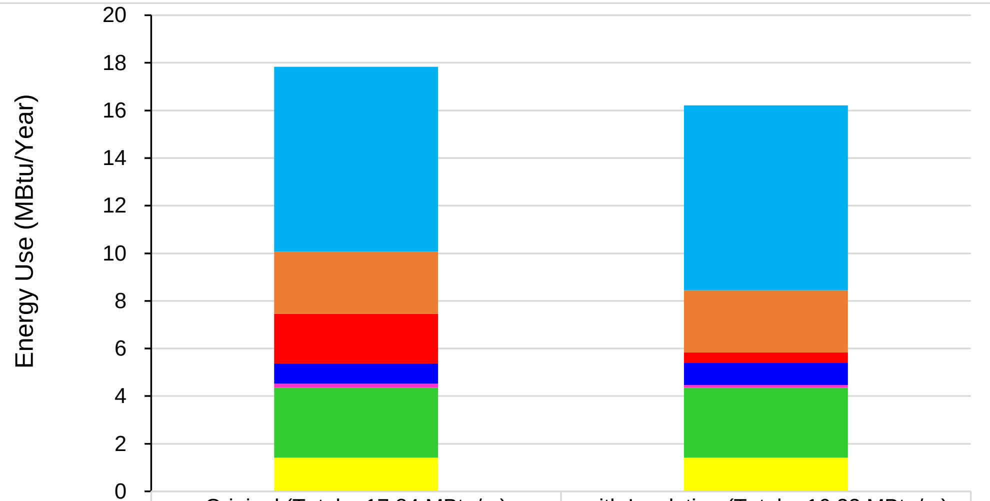
should be applied to the existing mass wall. The exterior coating consisted of a painted 5mm cement mortar.



1 – Exterior Wall   2 – Adhesive   3 – EPS Board   4 – Water Proofing
5 – Cement Mortar   6 – Exterior Paint   7 – Mechanical Fastener

Figure 5.16 External Insulation Thermal System with EPS Insulation. 1-7: interior-exterior

The result of simulation showed, the annual heating energy use greatly reduced. As shown in Figure 5.17, with the insulation, the energy use for space heating decreased by 79% from 2.08 MBtu/yr to 0.43 MBtu/yr, while the energy use for space cooling increased by 13% from 0.84 MBtu/yr to 0.95 MBtu/yr. This change showed that the insulation reduced the wall heat loss in the winter, which saved space heating energy use. However, the added insulation blocked the building heat loss at summer night through the uninsulated walls, which slightly increased the cooling load. Therefore, the total energy use decreased by 9.1% from 17.84 MBtu/yr to 16.22 MBtu/yr.



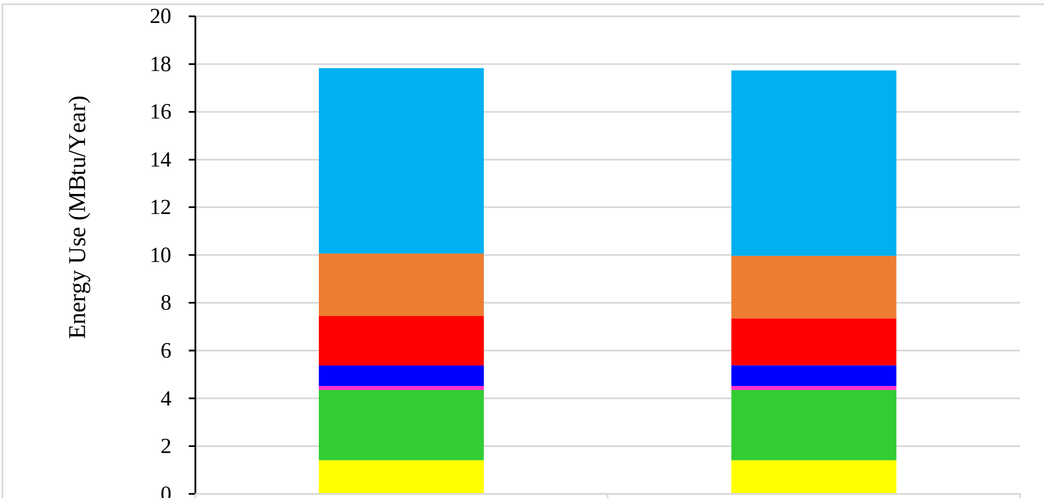
	Original (Total = 17.84 MBtu/yr)	with Insulation (Total = 16.22 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	0.43
Space Cooling	0.84	0.95
Ventilation Fan	0.17	0.11
Appliance	2.94	2.94
Lighting	1.42	1.42

Figure 5.17 Comparison of the Annual Energy Use of the Base Case and the Retrofit with Added Wall Insulation

5.3.4 Window Improvements

In this analysis, improved windows were added to the building. In the winter, there is a significant heating demand. Therefore, the thermal transmittance of the glazing was reduced to lower the heat loss through conduction. The base-case building has glazing with a U-Value of 0.65 Btu/h-ft^2-F and SHGC of 0.76. In the new windows, the U-Value was reduced to 0.49 Btu/h-ft^2-F by adding a thermal break to the aluminum frames, which improved the thermal insulation. The SHGC remained unchanged at 0.76. The results of the simulation were shown in Figure 5.18. With this new type of glazing, the energy use for space heating was reduced by 5.8% from 2.08 MBtu/yr to 1.96 MBtu/yr, while the energy use for space cooling increased by

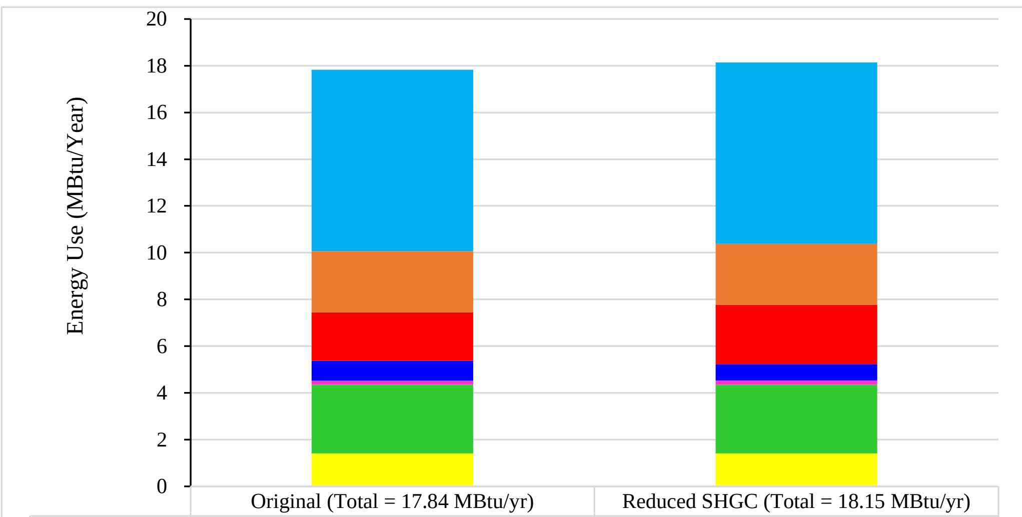
2.4% from 0.84 MBtu/yr to 0.86 MBtu/yr. Overall, the total annual energy use decreased by 0.6%, which is a small savings.



	Original (Total = 17.84 MBtu/yr)	Reduced U-Factor (Total = 17.74 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	1.96
Space Cooling	0.84	0.86
Ventilation Fan	0.17	0.17
Appliance	2.94	2.94
Lighting	1.42	1.42

Figure 5.18 Comparison of the Annual Energy Use of the Base Case and the Window Retrofit

In summer, to prevent solar thermal into space through the windows, the SHGC of the glazing should be reduced. According to ASHRAE Standard 90.1-2013, for Climate Zone 3A, the maximum SHGC is 0.25. With the U-Value reduced from 0.65 Btu/h-ft^2-F to 0.49 Btu/h-ft^2-F in previous retrofit, the SHGC was further reduced from 0.76 to 0.25. Unfortunately, the simulation showed that the total annual energy use for the apartment actually increased, as shown in Figure 5.19. Although the energy use for space cooling reduced by 16.7% from 0.84 MBtu/yr to 0.7 MBtu/yr, the energy use for space heating increased by 38.5% from 2.08 MBtu/yr to 2.54 MBtu/yr, and the total annual energy use increased by 1.7%. However, this does not mean that the low SHGC glazing is not appropriate for Warm-Humid Climate Zone 3A. As discussed in previous chapter, the case-study apartment uses blinds to block the sunlight through the window, it has natural ventilation and electric fan ventilation instead of system cooling, and most windows of the apartment face to the east. According to the apartment construction information and user's behavior, the low SHGC window is not appropriate for the case-study apartment. On the other hand, if there are no shading devices and the systems are used as much as required, low SHGC windows could help to save energy. This situation was not simulated in this research.

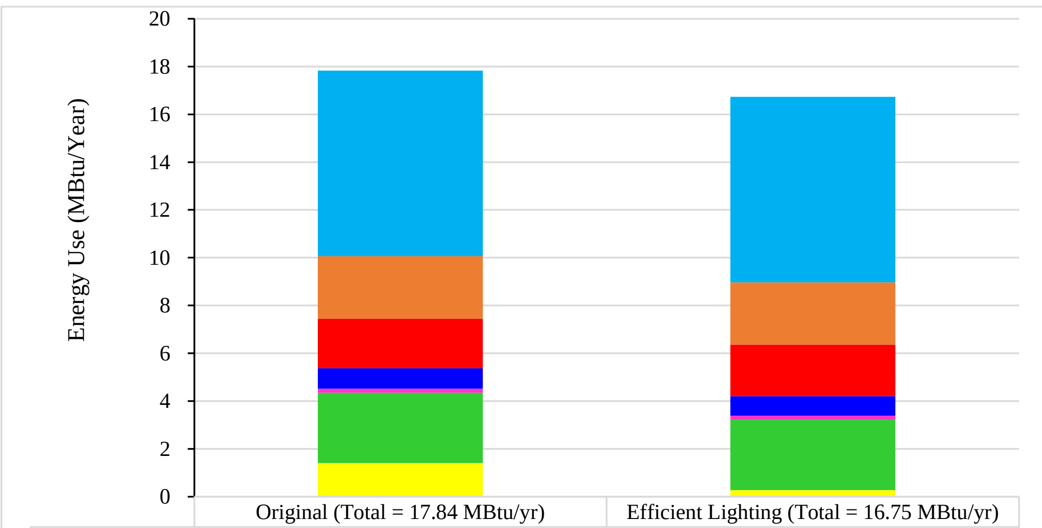


	Original (Total = 17.84 MBtu/yr)	Reduced SHGC (Total = 18.15 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	2.54
Space Cooling	0.84	0.70
Ventilation Fan	0.17	0.18
Appliance	2.94	2.94
Lighting	1.42	1.42

Figure 5.19 Comparison of the Annual Energy Use of the Base Case and the Retrofit of Low SHGC Glazing

5.3.5 Energy Efficient Lighting

In this energy efficiency measure, the incandescent lamps in the apartment were replaced with LED lamps. The new lamps were assumed to maintain the same illuminance level as the original ones for each space. From Figure 5.20, the results showed that the annual energy use for lighting was reduced by 80.3% from 1.42 MBtu/yr to 0.28 MBtu/yr. Overall, the total annual energy use was reduced by 6.1% from 17.84 MBtu/yr to 16.75 MBtu/yr, although there was slight increase for space heating and decrease for space cooling energy use.



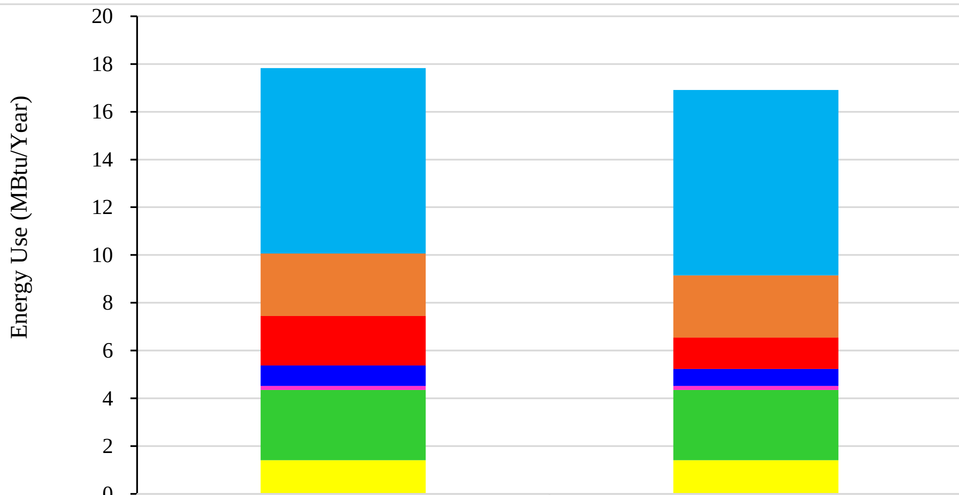
	Original (Total = 17.84 MBtu/yr)	Efficient Lighting (Total = 16.75 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	2.15
Space Cooling	0.84	0.82
Ventilation Fan	0.17	0.17
Appliance	2.94	2.94
Lighting	1.42	0.28

Figure 5.20 Comparison of the Annual Energy Use of the Base Case and the Retrofit of LED Lighting

5.3.6 High Efficiency HVAC Systems

This strategy aimed at increasing the efficiency of heating and air conditioning systems in the apartment. Two new HVAC systems with SEER-14 and HSPF-14 were used to replace the existing systems with SEER-12/10 and HSPF-11/10.

Figure 5.21 shows that with the new systems, the space heating energy use decreased by 37% from 2.08 MBtu/yr to 1.31 MBtu/yr; the space cooling energy use was reduced by 15.5% from 0.84 MBtu/yr to 0.71 MBtu/yr; the total annual energy use was reduced by 5.1% from 17.84 MBtu/yr to 16.93 MBtu/yr.



	Original (Total = 17.84 MBtu/yr)	New System (Total = 16.93 MBtu/yr)
Water Heating	7.76	7.76
Cooking	2.61	2.61
Space Heating	2.08	1.31
Space Cooling	0.84	0.71
Ventilation Fan	0.17	0.17
Appliance	2.94	2.94
Lighting	1.42	1.42

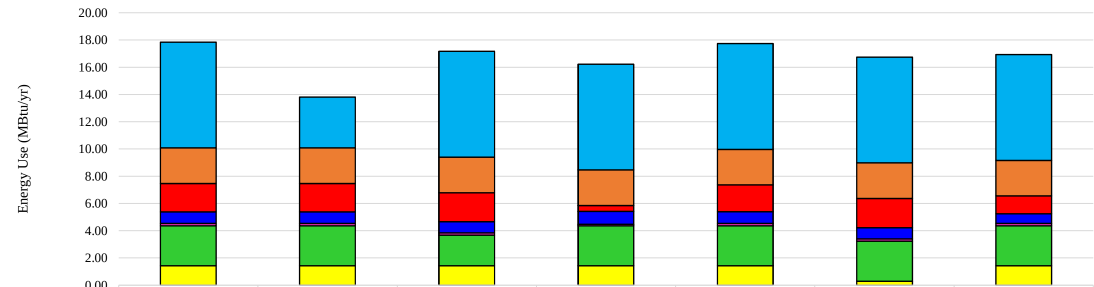
Figure 5.21 Comparison of the Annual Energy Use of the Base Case and the Retrofit of High Efficiency HVAC Systems

5.3.7 Individual and Combined Application of Energy Efficient Measures

Figure 5.22 shows the annual energy use for the individual energy-saving measures to the base-case apartment. The heat pump water heater had the most energy savings of 22.6% for the total annual energy use. The insulation was an effective strategy to save energy for space heating. The use of high efficiency refrigerator, lighting and air conditioning also increased savings in each category. However, they did not have a large reduction in the total energy use.

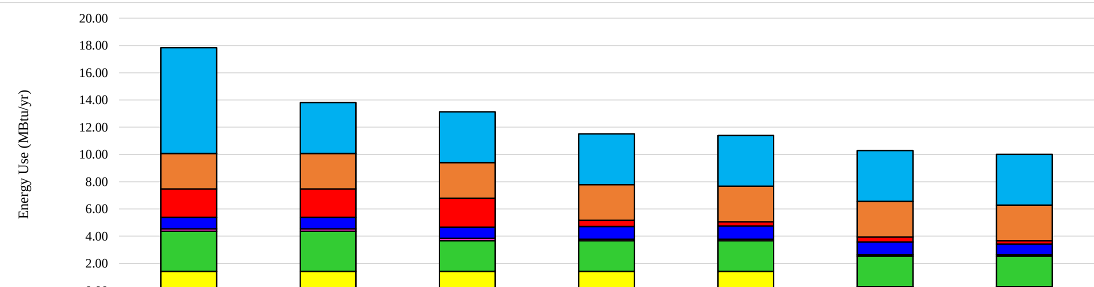
Figure 5.23 showed the results of the combined application of the energy efficient measures. In this analysis, when all the measures were combined, the total energy use was reduced by 43.9% from 17.84 MBtu/yr to 10.01 MBtu/yr. The largest energy savings came from heat pump water heater, which saved 4.03 MBtu/yr for the water heating. The application of insulation ranked second in energy savings, which saved 1.63 MBtu/yr for space conditoning. Lighting ranked third with an energy savings of 1.11 MBtu/yr. The replacement of refrigerator had a savings in the appliance energy use, but only showed 0.67 MBtu/yr savings in the total energy use. This was because the high efficiency refrigerator rejected less heat to the space, which reduced the cooling load but increased more heating load.

As shown in Figure 5.23 and Figure 5.24, the replacement of HVAC system had effect on the space cooling and heating energy use. Similarly, the thermal break for the window frame also had a small effect on the space cooling and space heating. There was no change for the cooking end use, which was because the natural gas stove is already the primary choice for Chinese households, and no new technologies to enhance the efficiency of the natural gas stove were found.



	Base Case (Total = 17.84 MBtu/yr)	HPWH (Total = 13.81 MBtu/yr)	High Efficiency Refrigerator (Total = 17.16 MBtu/yr)	With Insulation (Total = 16.22 MBtu/yr)	Thermal Break Window (Total = 17.74 MBtu/yr)	Improved Lighting (Total = 16.75 MBtu/yr)	High Efficiency HVAC (Total = 16.93 MBtu/yr)
Water Heating	7.76	3.73	7.76	7.76	7.76	7.76	7.76
Cooking	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Space Heating	2.08	2.08	2.12	0.43	1.96	2.15	1.31
Space Cooling	0.84	0.84	0.82	0.95	0.86	0.82	0.71
Ventilation Fan	0.17	0.17	0.17	0.11	0.17	0.17	0.17
Appliance	2.94	2.94	2.25	2.94	2.94	2.94	2.94
Lighting	1.42	1.42	1.42	1.42	1.42	0.28	1.42

Figure 5.22 Comparison of the Annual Energy Consumption of Base Case and Individual Energy-Efficiency Measures



	Base Case (Total = 17.84 MBtu/yr)	+ HPWH (Total = 13.81 MBtu/yr)	+ High Efficiency Refrigerator (Total = 13.14 MBtu/yr)	+ Insulation (Total = 11.51 MBtu/yr)	+ Improved Window (Total = 11.40 MBtu/yr)	+ Improved Lighting (Total = 10.29 MBtu/yr)	+ High Efficiency HVAC (Total = 10.01 MBtu/yr)
Water Heating	7.76	3.73	3.74	3.73	3.72	3.73	3.73
Cooking	2.61	2.61	2.61	2.61	2.61	2.61	2.61
Space Heating	2.08	2.08	2.12	0.46	0.31	0.37	0.25
Space Cooling	0.84	0.84	0.82	0.93	0.97	0.94	0.78
Ventilation Fan	0.17	0.17	0.17	0.11	0.11	0.11	0.11
Appliance	2.94	2.94	2.25	2.25	2.25	2.25	2.25
Lighting	1.42	1.42	1.42	1.42	1.42	0.28	0.28

Figure 5.23 Comparison of the Annual Energy Use of Base Case and Combined Energy-Efficiency Measures

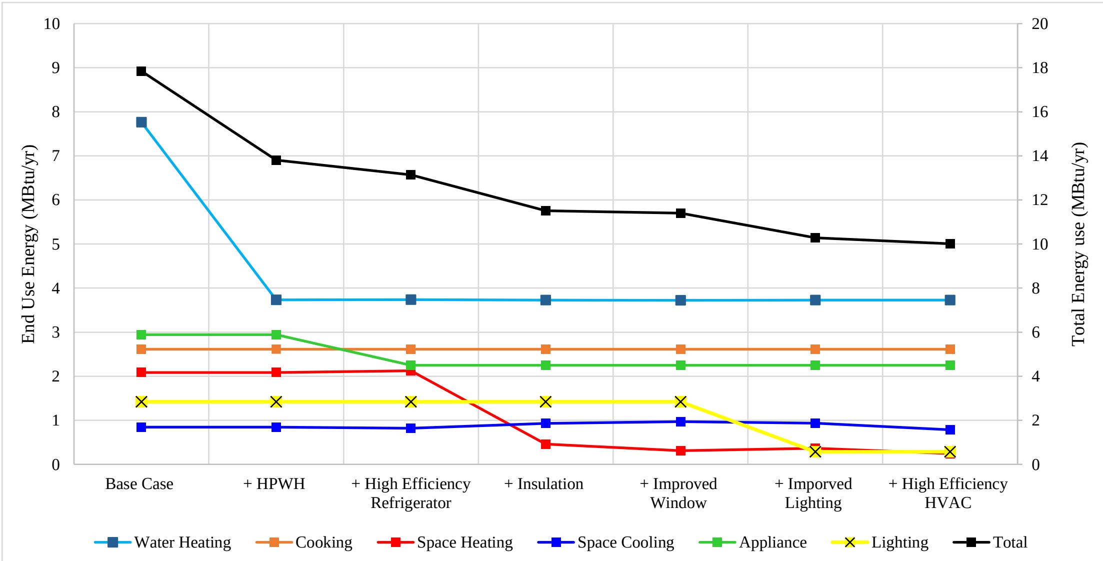


Figure 5.24 Effect of Combined Application of Energy Efficiency Measures on Annual Energy Use

The energy end-use with the combined EEMs was reduced by 43.9% compared to the base-case model, as shown in Figure 5.25. It also showed a large reduction for space heating and lighting energy use. The water heating energy use had also been greatly reduced as previously stated, but still had the largest share as 37% of the total energy use.

The case study apartment is on the 8th floor. Although energy use from the other apartments in the building could be very different due to the orientation, floor height, occupants and life schedules, if the measures applied to this apartment were applied to the whole building, then similar savings should be expected. By scaling the savings for the whole building based on the floor area of total apartments (exclude public area), the annual savings of the building with EEMs could be 1776 MBtu/yr.

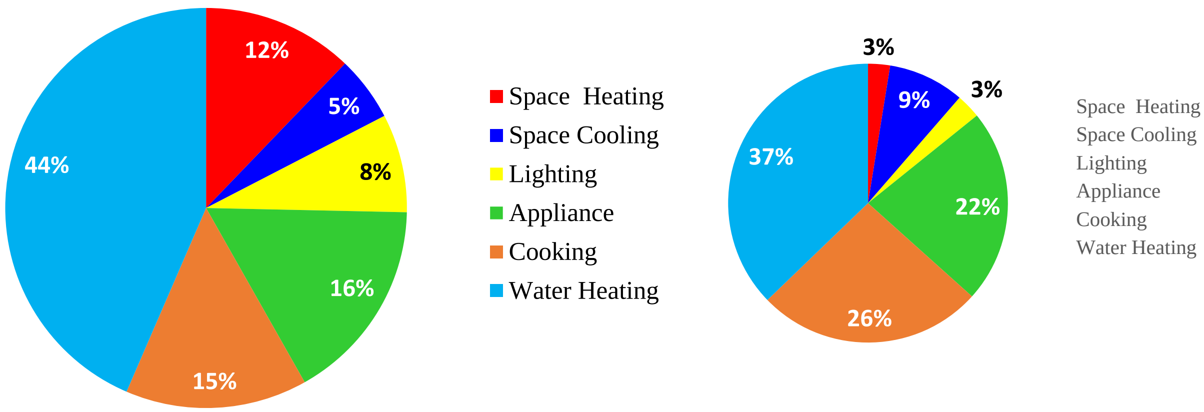


Figure 5.25 Comparison of Annual Energy End Use of Base Case and Combined EEMs

5.4 Cost Analysis

The simple payback method was used for the cost analysis of the energy efficient apartment. Simple payback considers the initial investment costs from energy efficient measures and the resulting annual energy cost savings. The payback period is the amount of time (in years) to recover the initial cost.

As shown in Table 5.6, the use of LED lamps has the shortest payback of less than one year, which is a very cost effective energy efficient measure. The high efficiency refrigerator has a payback period over 10 years, which is not attractive to most homeowner, since many refrigerator do not last 10 years. The wall insulation has a payback period of nearly 20 years. Unfortunately, the HPWH increased the energy cost because of the fuel switching. The existing water heater uses natural gas, and the HPWH uses electricity. As discussed in previous chapter, the unit cost for natural gas is ¥ 2.35/m^3 ($ 0.38/m^3), which corresponds to ¥ 67.14/MBtu ($ 10.75/MBtu); the unit cost for electricity is ¥ 0.617/kWh ($ 0.10/kWh), which corresponds to ¥180.83/MBtu ($

28.94/MBtu). It is much more expensive to use electricity than natural gas for the same energy use. Although switching to HPWH saves a lot of energy, it cost more than the existing natural gas water heater. So it has negative cost savings. The improvement of window frame with a thermal break has 41.4-year payback period. The high efficiency HVAC system has a very long payback period. Besides high initial cost, low annual energy cost savings is another important reason for this, because the case-study apartment did not use the HVAC system as much as required (e.g. natural or fan ventilation were used instead of system cooling). If the system was normally used, there could be much more energy and cost savings.

As a result, the high efficient lighting is the most cost effective energy efficient measure. The high efficient refrigerator and HVAC systems have long payback periods. The combined energy efficient measures have a payback of 57 years. However, if the HPWH is excluded from the EEMs, the payback period could be 30.9 years, and the ¥ 665 ($107) annual savings is still very attractive for homeowners. Therefore, the energy efficient appliance, lighting fixtures, and HVAC systems should be encouraged when residents plan to purchase new ones or replace the existing ones.

Table 5.6 Payback of Individual and Combined EEMs

Energy Efficient Measures (EEMs)	Initial Cost ¥ ($)	Base Case Energy Cost ¥/yr ($/yr)	With EEMs Energy Cost ¥/yr ($/yr)	Energy Cost Savings ¥/yr ($/yr)	Simple Estimated Payback yrs
HPWH	8,054 (1,291)	1,913 (307)	2,067 (331)	-154 (-25)	
High Efficiency Refrigerator	**1,368 (219)**	**1,913 (307)**	**1,793 (288)**	**120 (19)**	**11.4**
Insulation and Finish Systems	**4,034 (647)**	**1,913 (307)**	**1,706 (274)**	**207 (33)**	**19.5**
Window Frame with Thermal Break	640 (103)	1,913 (307)	1,897 (304)	15 (2)	42.7
LED bulbs	**123 (20)**	**1,913 (307)**	**1,719 (276)**	**194 (31)**	**0.6**
High Efficiency HVAC	13,798 (2,212)	1,913 (307)	1,784 (286)	129 (21)	107.3
Combined EEMs	28,637 (4,592)	1,913 (307)	1,483 (238)	430 (69)	57.3
Combined EEMs w/o HPWH	**20,583 (3,300)**	**1,913 (307)**	**1,248 (200)**	**665 (107)**	**30.9**

5.5 Summary

This Chapter presented the process of the as-built model calibration against utility bills. This chapter also presented the typical energy use of the case-study apartment and investigated energy efficient strategies applicable to the case-study apartment. The economic feasibility of the measures were also discussed.

The case study apartment model was created based on the information from site visits, as-built drawings, and measured data. The building geometry, construction material values were first based on information from the as-built drawings. In addition, the internal loads from lighting and appliances were estimated by information from the residents according to the usage. The parameters of the HVAC systems were from the nameplates on the equipment. Based on the utility billing data, a 5-parameter model was used to represent the building energy performance with respect to outdoor air temperature. This model helped to identify the empirical thermostat setpoints for heating and cooling in the simulation model.

A calibration process was then performed by changing certain parameters in the model, including: (1) the use of natural ventilation for free cooling; (2) adjusting equipment power density; (3) resetting thermostat setpoints; (4) making up window blinds schedule; (5) adjusting bedroom conditioning schedule; (6) adjusting living room conditioning schedule; (7) tuning equipment power density. Finally, the difference between the simulated energy use and the measured data reduced to CV(RMSE) of 14.7% and MBE of -1.7%,which was considered adequate for calibration.

Natural gas use in the case-study apartment was simulated based on the existing kitchen burner and instantaneous water heater. By adjusting the hot water flow rate, the model was calibrated to match with the utility billing data to an acceptable level, with CV(RMSE) of 12.88% and NMBE of -4.26%.

The typical household energy use analysis revealed that the case-study family used most energy on water heating, then appliances and cooking. According to the residents' lifestyle, the apartment has both heating and cooling loads, but the heating loads is dominant. It is out of expectation that the residents use less electricity than natural gas, but they paid more on electricity than natural gas.

The energy-efficiency measures analyzed included: HPWH, high-efficiency refrigerator, wall insulation, window frame with thermal break, high-efficiency lighting and high-efficiency HVAC systems. Among these measures, HPWH had the most annual energy savings of 22.6%; insulation ranked second with 9.1% and lighting as third with 6.1%. With combined measures, the annual energy savings were 43.9%. End-use energy for space heating and lighting was greatly reduced in the total energy use. Although end use energy for water heating greatly reduced, it still had the largest portion in the total energy use.

For the cost analysis, simple payback method was used to calculate the annual energy cost savings and payback period for individual and combined measures. High-efficiency lighting has the payback period of less than 1 year. High-efficiency refrigerator had a long payback period due to high initial cost. Insulation had a payback period of nearly 20 years, but it was acceptable comparing to the life of the building.

Improving window frame with thermal break did not have obvious cost-effectiveness. High-efficiency HVAC system had a long payback period due to the high initial cost and low energy cost savings from low usage. HPWH increased the energy cost due to a higher rate of electricity than natural gas. If combined all the measures, the annual energy savings was ¥ 430 ($69), payback period was 57.3 years; if excluding HPWH from the measures, the annual energy savings was ¥ 665 ($107), and the payback period was reduced to 30.9 years.

6 CONCLUSIONS AND RECOMMENDATIONS

This section provides conclusion and proposes recommendations for future research in this area. The conclusions are presented to form guidelines to enhance high-rise residential energy-efficiency in Shanghai.

6.1 Conclusions

This research analyzed the energy use of an existing high-rise apartment in Shanghai, by applying some retrofit measures and economic analysis, the following points were concluded for achieving energy efficient high-rise residential buildings in Shanghai.

1) Domestic hot water uses the most end use energy for the case-study apartment. Replacement of the existing natural gas water heater with heat pump water heater saved over 20% of the total annual energy. However, this replacement increases annual energy use costs, which is due to the much higher unit cost of electricity than natural gas.

2) High efficiency appliances such as a refrigerator helps to save energy. However, since the initial cost is relatively high, the payback period is long.

3) Insulation is an effective strategy to reduce space heating energy use. For the case-study apartment, with the attachment of insulation to the outside of exterior wall, the space heating energy use was reduced by 80%. Considering Shanghai's weather condition, it is highly recommended that the new buildings should include insulation during construction, and for the existing buildings with no insulation, retrofit should be conducted.

4) Double-pane windows are an effective way to prevent heat loss in winter and block solar heat gain in summer. The window frame with thermal break helps to save energy.

5) The use of LED lamps is a both energy efficient and cost effective way of life. For the case-study apartment, replacement of incandescent bulb with LED lamps helps saving 80% of the lighting energy use and 6% total energy use. The payback for the initial cost is less than 1 year. Energy efficient lighting is highly recommended for families.

6) High efficiency HVAC system helps to save energy for space heating and cooling, but the payback period is long due to the low energy cost savings besides the high initial cost. The existing system was not used as much as required, and the low usage ended up with low energy and cost savings. As people are willing to have more comfortable indoor environment, the system will get more usage, the cost effectiveness of the high-efficiency HVAC system will finally be obtained.

7) The combination of energy efficient measures (except HPWH) has both energy and cost advantages. Refer to the case-study apartment, ¥ 665 ($ 107) annual energy savings is attractive, especially for new homeowners.

8) The proposed EEMs could be a solution to meet the city's growing residential energy use, which saves the government time and money to build new power plants. It is suggested that the government take actions to encourage manufacturers to produce high-efficiency products at lower costs and also encourage customers to purchase them.

6.2 Recommendations for Future Research

In the analysis of HPWH, this retrofit did not get economic benefit, one reason is that the equipment was used at normal electric rate period (from 6am to 10pm). One suggestion is to have the water heated after 10pm when the electric rate is only the half price, the hot water is then stored in the well-insulated tank for daily use. This could get some cost effectiveness, which need to be verified in the future work.

For this research, space heating, cooling, lighting, appliances, domestic water heating energy use were considered. Thermal comfort was not analyzed. Currently, reduced energy use for space heating, cooling was achieved without changing the thermal comfort of the existing occupants. However, with the growing living cost, people would prefer more comfortable indoor environment in respect of room air temperature, ventilation, room air quality, etc., which could be analyzed in future research.

This thesis analyzed energy efficient measures that were simulatable with the eQuest program. This excluded the analysis of renewable energy saving measures such as solar thermal, solar PV and wind turbine. Since high-rise buildings have great potential to use energy from the sun and wind, the renewable energy technologies should also be evaluated in future research.

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APPENDIX A

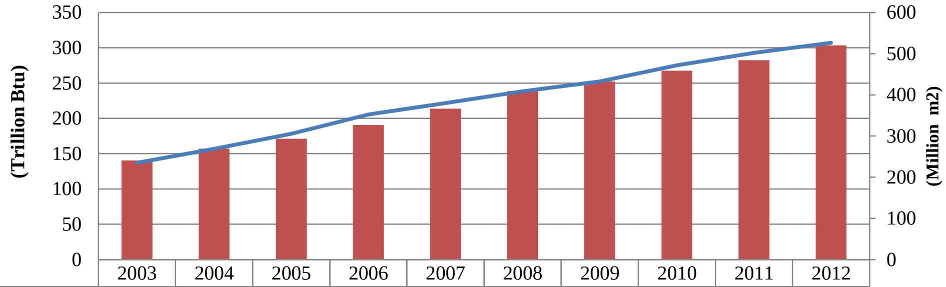
INFORMATION OF HIGH-RISE RESIDENTIAL BUILDINGS IN SHANGHAI AND

THE CASE-STUDY APARTMENT

A 1. Background Information of High-Rise Residential Buildings in Shanghai.

Figure A-1: Cathay Mansion – The First High-Rise Residential Building in Shanghai
http://www.51zhaolou.com/dis_mzml.asp?id=179 (Accessed on May 21, 2013)

Figure A-2: The Urban Sprawl Plan in Shanghai, 2012.
http://www.shanghai.gov.cn/shanghai/node2314/node2319/node10800/node11407/node29273/u26ai34426.html (Accessed on March 20, 2013)



	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Residential building energy use (Trillion Btu)	140.4	157.0	171.2	190.5	213.6	238.5	252.3	267.5	282.3	303.3
Residential building are (Million m2)	234.75	269.06	305.6	352.11	379.97	408.57	432.83	471.95	502.11	526.4

Figure A-3 Residential Building Energy Use and Area in Shanghai between 2003 and 2012. 2013 Shanghai Statistical Yearbook. Retrieved from: http://www.stats-sh.gov.cn/data/toTjnj.xhtml?y=2013 (accessed May 15, 2014)

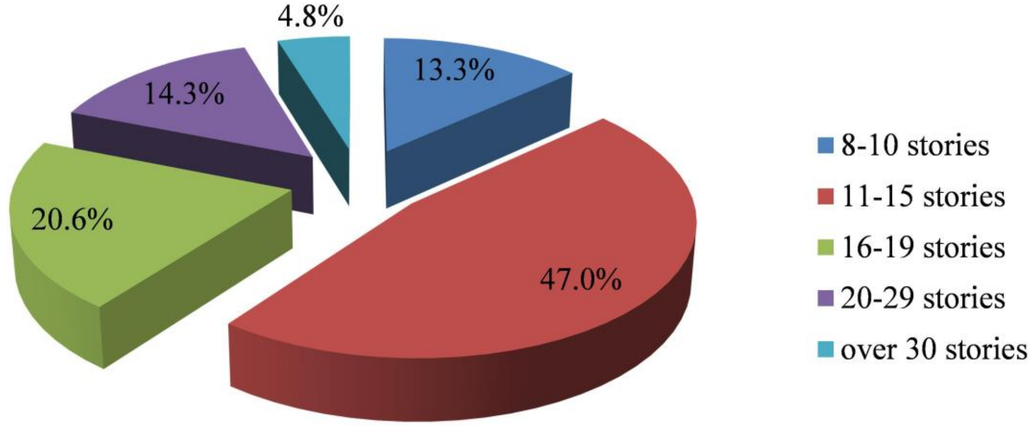


Figure A-4 Shanghai Residential Building Categories by Floor Number in 2010. Buildings with 11 to 15 stories had the greatest portion. Buildings with less than 8 floors were not included in this calculation due to their small amount. 2011 Shanghai Statistical Yearbook. Retrieved from: http://www.stats-sh.gov.cn/data/toTjnj.xhtml?y=2011 (accessed May 15, 2014).

A 2. Equipment Proposed in EEMs for Case Study Apartment

The proposed EEMs in this research include: HPWH, high efficiency refrigerator, window frame with thermal break, LED lighting, and high-efficiency HVAC system. Real products were used in the analysis. The products were simulated with the parameters from their specifications, the prices of the products were used for economy analysis.

A 2.1 HPWH is a product from GE Company. It has a 50 gallon water tank, hybrid electric HPWH with an electric resistance back up heat source. The overall energy factor is 2.4

Figure A-5 GE GeoSpring Hybrid Electric Water Heater (GEH50DEEDSR) http://products.geappliances.com/ApplProducts/Dispatcher?REQUEST=SpecPage&Sku=GEH50DEEDSR (Accessed on May 26, 2014).

A 2.2 The new refrigerator is a product from Haier Company, it uses 0.49 kWh per day.

Figure A-6 Haier Energy-Efficiency Refrigerator (BCD-186KB)
http://www.haier.com/cn/consumer/cooling/lmbx/201203/t20120308_114402.shtml
(Accessed on May 26, 2014)

A 2.3 The overall U-Value for a window frame with thermal break was from the DOE2 glass library, and its cost was referred to the information of a manufacturer in Shanghai.

Figure A-7 Thermal Break between the Interior and Exterior Frames.
http://detail.1688.com/offer/1220238661.html (Accessed on May 26, 2014)

A 2.4 LED bulbs are from PHILIPS Company. The new bulbs have the same illuminance level as the existing incandescent bulbs.

Figure A-8 LED Bulb from PHILIPS
http://www.philips.com.cn/c/led-lightbubls/35232/cat/#filterState=LED_BULB_SU_CN_CONSUMER;LED_CANDLE_SU_CN_CONSUMER;#Comparison=;#nowpage=1 (Accessed on May 26, 2014)

A 2.5 The high efficiency HVAC system is a product from Haier Company. The new system has the same heating/cooling capacity as the existing one, but higher SEER and HSPF. A new feature of this system is dehumidification.

Figure A-9 Haier Energy-Efficiency HVAC System (KFR-35GW/03CAA21A) http://www.haier.com/cn/consumer/air_conditioners/bgskt/201307/t20130705_174495.shtml (Accessed on May 26, 2014)

APPENDIX B

CASE-STUDY APARTMENT ENERGY USE SIMULATION INPUT FILE IN EQUEST

This research used eQUEST (v3.64) as the simulation program. The building geometry was input in the wizard mode of the program. The detailed information for the construction, schedules, internal loads, and system parameters were input in the detailed interface of the program. This section has two parts: the input file for the calibrated case-study apartment model, and simulation of the EEMs.

B 1. Simulation Input File

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be redistributed or sold without written approval from the author.

```
INPUT ..

$ ---------------------------------------------------------
$              Abort, Diagnostics
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Global Parameters
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Title, Run Periods, Design Days, Holidays
$ ---------------------------------------------------------

TITLE
   LINE-1          = *Thesis project (3Zone)Detail-Original*
```

```
   ..

"Entire Year" = RUN-PERIOD-PD
   BEGIN-MONTH      = 1
   BEGIN-DAY        = 1
   BEGIN-YEAR       = 2011
   END-MONTH        = 12
   END-DAY          = 31
   END-YEAR         = 2011
   ..


"Observed Holidays" = HOLIDAYS
   TYPE             = ALTERNATE
   MONTHS           = ( 1, 2, 2, 2, 4, 5, 6, 9, 10, 10, 10 )
   DAYS             = ( 3, 2, 3, 4, 4, 2, 6, 12, 3, 4, 5 )
   ..


$ ---------------------------------------------------------
$              Compliance Data
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Site and Building Data
$ ---------------------------------------------------------

"Site Data" = SITE-PARAMETERS
   ..

"Building Data" = BUILD-PARAMETERS
   HOLIDAYS         = "Observed Holidays"
   ..



$ ---------------------------------------------------------
$              Materials / Layers / Constructions
$ ---------------------------------------------------------

"Com Brick 4in (HF-C4)" = MATERIAL
   LIBRARY-ENTRY "Com Brick 4in (HF-C4)"
   ..
"CMU HW 4in PartFill (CB04)" = MATERIAL
   LIBRARY-ENTRY "CMU HW 4in PartFill (CB04)"
   ..
"Conc LW 40lb 8in (HF-C16)" = MATERIAL
   LIBRARY-ENTRY "Conc LW 40lb 8in (HF-C16)"
   ..
```

```
"Conc HW 140lb 8in (CC05)" = MATERIAL
   LIBRARY-ENTRY "Conc HW 140lb 8in (CC05)"
   ..
"Wood Hd 3/4in (WD11)" = MATERIAL
   LIBRARY-ENTRY "Wood Hd 3/4in (WD11)"
   ..
"Asph Roll Roof (AR01)" = MATERIAL
   LIBRARY-ENTRY "Asph Roll Roof (AR01)"
   ..
"Asph Siding (AR02)" = MATERIAL
   LIBRARY-ENTRY "Asph Siding (AR02)"
   ..
"Asph Tile (AR03)" = MATERIAL
   LIBRARY-ENTRY "Asph Tile (AR03)"
   ..
"Roof Insul 2in (IN74)" = MATERIAL
   LIBRARY-ENTRY "Roof Insul 2in (IN74)"
   ..
"Cmt Mortar 1in (CM01)" = MATERIAL
   LIBRARY-ENTRY "Cmt Mortar 1in (CM01)"
   ..
"Stucco 1in (SC01)" = MATERIAL
   LIBRARY-ENTRY "Stucco 1in (SC01)"
   ..
"Com Brick 4in (BK01)" = MATERIAL
   LIBRARY-ENTRY "Com Brick 4in (BK01)"
   ..
"Felt 3/8in (HF-E3)" = MATERIAL
   LIBRARY-ENTRY "Felt 3/8in (HF-E3)"
   ..

"Ground Floor Cons Lyr" = LAYERS
   INSIDE-FILM-RES  = 0.92
   MATERIAL         = ( "Conc HW 140lb 8in (CC05)", "Wood Hd 3/4in
(WD11)" )
   ..
"Roof Cons Lyr" = LAYERS
   INSIDE-FILM-RES  = 0.62
   MATERIAL         = ( "Felt 3/8in (HF-E3)", "Roof Insul 2in
(IN74)",
         "Conc HW 140lb 8in (CC05)", "Stucco 1in (SC01)" )
   THICKNESS        = ( 0.066, &D, &D, 0.033 )
   ..
"Ext Wall Cons Lyr" = LAYERS
   INSIDE-FILM-RES  = 0.68
   MATERIAL         = ( "Stucco 1in (SC01)", "Conc HW 140lb 8in
(CC05)",
         "Stucco 1in (SC01)" )
   THICKNESS        = ( 0.049, &D, 0.033 )
   ..
"EL1 IWall Cons Layers" = LAYERS
```

```
   MATERIAL         = ( "Stucco 1in (SC01)", "Com Brick 4in
(BK01)",
         "Stucco 1in (SC01)" )
   THICKNESS        = ( 0.033, 0.377, 0.033 )
   ..
"EL1 IFlr Cons Layers" = LAYERS
   MATERIAL         = ( "Stucco 1in (SC01)", "Conc HW 140lb 8in
(CC05)",
         "Wood Hd 3/4in (WD11)" )
   THICKNESS        = ( 0.033 )
   ..

"Ground Floor Cons" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Ground Floor Cons Lyr"
   ..
"Roof Cons" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Roof Cons Lyr"
   ..
"Ext Wall Cons" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Ext Wall Cons Lyr"
   ..
"EL1 IWall Construction" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "EL1 IWall Cons Layers"
   ..
"EL1 IFlr Construction" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "EL1 IFlr Cons Layers"
   ..


$ ---------------------------------------------------------
$              Glass Type Codes
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Glass Types
$ ---------------------------------------------------------

"EL1 Window Type #1 GT" = GLASS-TYPE
   TYPE             = SHADING-COEF
   SHADING-COEF     = 0.87
   GLASS-CONDUCT    = 0.75
   VIS-TRANS        = 0.81
   ..
```

```
$ -----------------------------------------------------------
$               Window Layers
$ -----------------------------------------------------------


$ -----------------------------------------------------------
$               Lamps / Luminaries / Lighting Systems
$ -----------------------------------------------------------



$ -----------------------------------------------------------
$               Day Schedules
$ -----------------------------------------------------------

"EL1 Bldg Occup WD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.9, &D, &D, &D, &D, &D, 0.702, 0.402, 0.3,
&D, &D,&D, &D, &D, &D, &D, 0.498, 0.9 )
   ..
"EL1 Bldg Occup WEH" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.9, &D, &D, &D, &D, &D, 0.895, 0.8462,
0.695, 0.5286, 0.5, &D, &D, &D, 0.5286, 0.695, 0.8462, 0.895, 0.9 )
   ..
"EL1 Bldg Occup HDD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0 )
   ..
"EL1 Bldg InsLt WD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, &D, &D, &D, &D, 0, 0, 0.3, 0, &D, &D,
&D, &D, &D, &D, &D, &D, 0.51, 0.84, &D, 0.73, 0.16, 0.16, 0.16 )
   ..
"EL1 Bldg InsLt WEH" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, 0, 0, &D, &D, 0, 0, 0, 0.3, 0, 0, 0, &D,
&D, &D, &D, 0, 0.51, 0.84, 0.84, 0.73, 0.16, 0.16, 0.16 )
   ..
"EL1 Bldg InsLt HDD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0 )
   ..
"EL1 Bldg Cook WD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, &D, &D, &D, 0, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0.5, 0, 0, 0, 0, 0 )
```

```
   ..
"EL1 Bldg Cook Sat" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, &D, &D, &D, 0.021, 0.028, 0.049, 0.098,
0.252, 0.147, 0.049, 0.119, 0.161, 0.098, 0.049, 0.203, 0.35, 0.7,
0.399, 0.238, 0.098, 0.049, 0.021 )
   ..
"EL1 Bldg Cook Sun" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, &D, &D, &D, 0.021, 0.028, 0.049, 0.098,
0.252, 0.203, 0.098, 0.119, 0.161, 0.098, 0.049, 0.252, 0.399, 0.7,
0.399, 0.203, 0.077, 0.021, 0.007 )
   ..
"EL1 Bldg Cook HDD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0 )
   ..
"EL1 Bldg Misc WD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.007, &D, &D, &D, &D, &D, 0.007, 0.26,
0.007, 0.07, &D, 0.007, 0.007, 0.07, 0.16, 0.07, 0.07, 0.73, 0.08,
0.14, 0.14, 0.05, 0.05, 0.05 )
   ..
"EL1 Bldg Misc WEH" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.007, 0.007, 0.007, &D, &D, &D, 0.007,
0.007, 0.26, 0.007, 0.007, 0.007, 0.007, 0.007, 0.007, 0.007,
0.007, 0.73, 0.08, 0.14, 0.14, 0.05, 0.05, 0.05 )
   ..
"EL1 Bldg Misc HDD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0 )
   ..
"DHW Eqp Res WD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0, &D, &D, &D, &D, 0, 0, 0, 0, 0, 0, 0, 0,
0, 0, 0, 0, 0, 0, 0.5, 0, 0, 0, 0 )
   ..
"DHW Eqp Res Sat" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.0804, 0.0536, 0.05, &D, &D, &D, 0.0573,
0.1154, 0.2663, 0.4651, 0.4714, 0.3256, 0.3155, 0.4681, 0.7551,
0.7154, 0.6871, 0.6308, 0.5511, 0.4665, 0.3815, 0.2975, 0.2178,
0.1384 )
   ..
"DHW Eqp Res Sun" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.0806, 0.0537, 0.05, &D, &D, &D, &D,
0.0536, 0.0892, 0.1956, 0.2691, 0.2274, 0.3026, 0.4332, 0.5675,
0.6455, 0.4694, 0.3368, 0.2532, 0.2065, 0.1995, &D, 0.1902, 0.1354
)
```

```
   ..
"DHW Eqp Res HDD" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0 )
   ..
"ZG0-S1 (RS2) P-Inf WD" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, &D, &D, &D, 0.944, 1.25, &D,
0.656, 0.5, &D, &D, &D, &D, &D, 0.944, 1.25, &D, 0.5 )
   ..
"ZG0-S1 (RS2) P-Inf WEH" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, &D, &D, &D, &D, 0.5113, 0.95,
1.25, 0.9349, 0.5, &D, &D, &D, 0.9349, 1.25, 0.95, 0.5113, 0.5 )
   ..
"ZG0-S1 (RS2) P-Inf HDD" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5 )
   ..
"ZG0-S1 (RS2) C-Inf All" = DAY-SCHEDULE-PD
   TYPE             = FRACTION
   VALUES           = ( 0.5 )
   ..
"S1 Sys1 (RS2) Fan All" = DAY-SCHEDULE-PD
   TYPE             = ON/OFF/FLAG
   VALUES           = ( 1 )
   ..
"S1 Sys1 (RS2) Cool All" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 79 )
   ..
"S1 Sys1 (RS2) Heat All" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 63 )
   ..
"ZG1-S1 (RS2) P-Inf WD" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, &D, &D, &D, 0.944, 1.25, &D,
1.052, 1, &D, &D, &D, &D, &D, 1.148, 1.25, &D, 0.5 )
   ..
"ZG1-S1 (RS2) P-Inf WEH" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, &D, &D, &D, &D, 0.5113, 0.95,
1.25, 1.145, 1, &D, &D, &D, 1.145, 1.25, 0.95, 0.5113, 0.5 )
   ..
"ZG1-S1 (RS2) P-Inf HDD" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, &D, &D, &D, &D, &D, &D, &D, 1, &D,
&D, &D, &D, &D, &D, 0.5 )
   ..
"ZG1-S1 (RS2) C-Inf WD" = DAY-SCHEDULE-PD
```

```
   TYPE              = FRACTION
   VALUES            = ( 0.5, &D, &D, &D, &D, &D, &D, 1, &D, &D, &D,
&D, &D, &D, &D, &D, &D, 0.5 )
   ..
"ZG1-S1 (RS2) C-Inf WEH" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 0.5, &D, &D, &D, &D, &D, &D, &D, &D, 1, &D,
&D, &D, &D, &D, &D, 0.5 )
   ..
"S2 Sys2 (RS2) Fan WD" = DAY-SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   VALUES            = ( 1, &D, &D, &D, &D, &D, &D, 0, &D, &D, &D,
&D, &D, &D, &D, &D, &D, 1 )
   ..
"S2 Sys2 (RS2) Fan WEH" = DAY-SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   VALUES            = ( 1, &D, &D, &D, &D, &D, &D, &D, &D, 0, &D,
&D, &D, &D, &D, &D, 1 )
   ..
"Cust 1 Elec TOU Seas1 Day1" = DAY-SCHEDULE-PD
   TYPE              = FLAG
   VALUES            = ( 1.4, &D, &D, &D, &D, &D, 1.2, &D, &D, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, &D, &D, &D, 1.4 )
   ..
"Custom Gas Seas1 Day" = DAY-SCHEDULE-PD
   TYPE              = FLAG
   VALUES            = ( 1 )
   ..
"Day Occup Master WD" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 1, &D, &D, &D, &D, &D, 1, 0, 0, &D, &D, &D,
&D, &D, &D, &D, 0, 0, 0, &D, 1 )
   ..
"Day Occup Master WEH" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 1, &D, &D, &D, &D, &D, 1, 1, 0, &D, &D, &D,
&D, &D, &D, &D, 0, 0, 0, &D, 0, &D, 1 )
   ..
"Day Occup Liv WD" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 0, &D, &D, &D, &D, &D, 0, 1, 0.5, &D, &D,
&D, &D, &D, &D, &D, 0.5, 1, 1, 1, 0 )
   ..
"Day Occup Liv WEH" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 0, &D, &D, &D, &D, &D, 0, 0, 1, &D, &D, &D,
0, &D, &D, &D, 1, 1, 1, 1, 1, &D, 0 )
   ..
"Day Occup Sm WD" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
```

```
   VALUES            = ( 0, &D, &D, &D, &D, &D, 0, 0, 0, &D, &D, &D,
&D, &D, &D, &D, 0, 0, 0, 0, 0 )
   ..
"Day Occup Sm WEH" = DAY-SCHEDULE-PD
   TYPE              = FRACTION
   VALUES            = ( 0, &D, &D, &D, &D, &D, 0, 0, 0, &D, &D, &D,
&D, &D, &D, &D, 0, 0, 0, 0, 0 )
   ..
"Day Sys (RS2) Cool Liv WD" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 110, &D, &D, &D, &D, &D, &D, 110, &D, &D,
&D, &D, &D, &D, &D, &D, &D, 82.5, &D, 110, 110 )
   ..
"Day Sys (RS2) Cool Liv WEH" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 110, &D, &D, &D, &D, &D, &D, 110, 82.5, &D,
110, 110, 110, &D, &D, &D, 82.5, &D, &D, 110, 110, &D, 110 )
   ..
"Day Sys (RS2) Heat Liv WD" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 40, &D, &D, &D, &D, &D, &D, 66, &D, &D, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, 40 )
   ..
"Day Sys (RS2) Heat Liv WEH" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 40, &D, &D, &D, &D, &D, &D, 40, 66, &D, &D,
&D, 40, &D, &D, &D, 66, &D, &D, &D, 66, &D, 40 )
   ..
"Day Sys (RS2) Cool Mst WD" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 110, &D, &D, &D, &D, &D, &D, 110, &D, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, &D, 82.5, &D, 110 )
   ..
"Day Sys (RS2) Cool Mst WEH" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 110, &D, &D, &D, &D, &D, &D, 110, 110, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, &D, 110, &D, 82.5 )
   ..
"Day Sys (RS2) Heat Mst WD" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 66, &D, &D, &D, &D, &D, &D, 40, &D, &D, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, 66 )
   ..
"Day Sys (RS2) Heat Mst WEH" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 66, &D, &D, &D, &D, &D, &D, 66, 40, &D, &D,
&D, &D, &D, &D, &D, &D, &D, &D, &D, 40, &D, 66 )
   ..
"Natural Vent Day" = DAY-SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   VALUES            = ( -1 )
```

```
   ..
"Vent Temp Day" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 68, &D, &D, &D, &D, &D, &D, 68, 68, &D, &D,
&D, 68, &D, &D, &D, 68, &D, &D, &D, 68, &D, 68 )
   ..
"Liv Blinds Summer day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0, &D, 0, &D, 0, &D, 0, 0, &D, &D, &D, &D,
&D, &D, &D, &D, &D, 0, &D, 0, 1 )
   ..
"Liv Blinds other day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 1, &D, 1, &D, 1, &D, 1, 1, &D, &D, &D, &D,
&D, &D, &D, &D, &D, 1, &D, 1, 1 )
   ..
"Liv Cond summer day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, 0.5, 0.5, 0.5, &D, 0.5, 0.5, &D,
&D, &D, &D, &D, &D, &D, &D, &D, 0.5, &D, 0.5, 1 )
   ..
"Liv Cond other day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 1, &D, 1, &D, 1, &D, 1, 1, &D, &D, &D, &D,
&D, &D, &D, &D, &D, 1, &D, 1, 1 )
   ..
"Mast Blinds day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0, &D, 0, &D, 0, &D, 0, 0, 1, &D, &D, &D,
&D, &D, &D, &D, &D, 1, &D, 1, 0 )
   ..
"Mast Cond day sch" = DAY-SCHEDULE-PD
   TYPE             = MULTIPLIER
   VALUES           = ( 0.5, &D, 0.5, &D, 0.5, &D, 0.5, 0.5, 1, &D,
&D, &D, &D, &D, &D, &D, &D, 1, &D, 1, 0.5 )
   ..
"Ground T Day Jan" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 53.4 )
   ..
"Ground T Day Feb" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 49.5 )
   ..
"Ground T Day Mar" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 49.2 )
   ..
"Ground T Day Apr" = DAY-SCHEDULE-PD
   TYPE             = TEMPERATURE
   VALUES           = ( 51.1 )
```

```
   ..
"Ground T Day May" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 58.6 )
   ..
"Ground T Day Jun" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 66.1 )
   ..
"Ground T Day Jul" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 72.5 )
   ..
"Ground T Day Aug" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 76.6 )
   ..
"Ground T Day Sep" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 77 )
   ..
"Ground T Day Oct" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 73.7 )
   ..
"Ground T Day Nov" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 67.3 )
   ..
"Ground T Day Dec" = DAY-SCHEDULE-PD
   TYPE              = TEMPERATURE
   VALUES            = ( 60.1 )
   ..

$ ---------------------------------------------------------
$               Week Schedules
$ ---------------------------------------------------------

"EL1 Bldg Occup Wk" = WEEK-SCHEDULE-PD
   TYPE              = FRACTION
   DAY-SCHEDULES     = ( "EL1 Bldg Occup WD", &D, &D, &D, &D,
         "EL1 Bldg Occup WEH", &D, &D, "EL1 Bldg Occup HDD",
         "EL1 Bldg Occup WEH" )
   ..
"EL1 Bldg InsLt Wk" = WEEK-SCHEDULE-PD
   TYPE              = FRACTION
   DAY-SCHEDULES     = ( "EL1 Bldg InsLt WD", &D, &D, &D, &D,
         "EL1 Bldg InsLt WEH", &D, &D, "EL1 Bldg InsLt HDD",
         "EL1 Bldg InsLt WEH" )
   ..
"EL1 Bldg Cook Wk" = WEEK-SCHEDULE-PD
```

```
   TYPE                = FRACTION
   DAY-SCHEDULES       = ( "EL1 Bldg Cook WD", &D, &D, &D, &D,
         "EL1 Bldg Cook WD", "EL1 Bldg Cook WD", &D, "EL1 Bldg Cook
WD",
         "EL1 Bldg Cook WD" )
   ..
"EL1 Bldg Misc Wk" = WEEK-SCHEDULE-PD
   TYPE                = FRACTION
   DAY-SCHEDULES       = ( "EL1 Bldg Misc WD", &D, &D, &D, &D,
         "EL1 Bldg Misc WEH", &D, &D, "EL1 Bldg Misc HDD",
         "EL1 Bldg Misc WEH" )
   ..
"DHW Eqp Res Wk" = WEEK-SCHEDULE-PD
   TYPE                = FRACTION
   DAY-SCHEDULES       = ( "DHW Eqp Res WD", &D, &D, &D, &D, "DHW Eqp
Res WD",
         "DHW Eqp Res WD", &D, "DHW Eqp Res WD", "DHW Eqp Res WD" )
   ..
"ZG0-S1 (RS2) P-Inf Wk" = WEEK-SCHEDULE-PD
   TYPE                = MULTIPLIER
   DAY-SCHEDULES       = ( "ZG0-S1 (RS2) P-Inf WD", &D, &D, &D, &D,
         "ZG0-S1 (RS2) P-Inf WEH", &D, &D, "ZG0-S1 (RS2) P-Inf
HDD",
         "ZG0-S1 (RS2) P-Inf WEH" )
   ..
"ZG0-S1 (RS2) C-Inf Wk" = WEEK-SCHEDULE-PD
   TYPE                = FRACTION
   DAY-SCHEDULES       = ( "ZG0-S1 (RS2) C-Inf All" )
   ..
"S1 Sys1 (RS2) Fan Wk" = WEEK-SCHEDULE-PD
   TYPE                = ON/OFF/FLAG
   DAY-SCHEDULES       = ( "S1 Sys1 (RS2) Fan All" )
   ..
"S1 Sys1 (RS2) Cool Wk" = WEEK-SCHEDULE-PD
   TYPE                = TEMPERATURE
   DAY-SCHEDULES       = ( "S1 Sys1 (RS2) Cool All" )
   ..
"S1 Sys1 (RS2) Heat Wk" = WEEK-SCHEDULE-PD
   TYPE                = TEMPERATURE
   DAY-SCHEDULES       = ( "S1 Sys1 (RS2) Heat All" )
   ..
"ZG1-S1 (RS2) P-Inf Wk" = WEEK-SCHEDULE-PD
   TYPE                = MULTIPLIER
   DAY-SCHEDULES       = ( "ZG1-S1 (RS2) P-Inf WD", &D, &D, &D, &D,
         "ZG1-S1 (RS2) P-Inf WEH", &D, &D, "ZG1-S1 (RS2) P-Inf
HDD",
         "ZG1-S1 (RS2) P-Inf WEH" )
   ..
"ZG1-S1 (RS2) C-Inf Wk" = WEEK-SCHEDULE-PD
   TYPE                = FRACTION
   DAY-SCHEDULES       = ( "ZG1-S1 (RS2) C-Inf WD", &D, &D, &D, &D,
```

```
         "ZG1-S1 (RS2) C-Inf WEH", &D, &D, "ZG1-S1 (RS2) C-Inf
WEH",
         "ZG1-S1 (RS2) C-Inf WEH" )
   ..
"S2 Sys2 (RS2) Fan Wk" = WEEK-SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   DAY-SCHEDULES     = ( "S2 Sys2 (RS2) Fan WD", &D, &D, &D, &D,
         "S2 Sys2 (RS2) Fan WEH", &D, &D, "S2 Sys2 (RS2) Fan WEH",
         "S2 Sys2 (RS2) Fan WEH" )
   ..
"Cust 1 Elec TOU Seas1 Week" = WEEK-SCHEDULE-PD
   TYPE              = FLAG
   DAY-SCHEDULES     = ( "Cust 1 Elec TOU Seas1 Day1" )
   ..
"Custom Gas Seas1 Week" = WEEK-SCHEDULE-PD
   TYPE              = FLAG
   DAY-SCHEDULES     = ( "Custom Gas Seas1 Day" )
   ..
"Week Occup Master" = WEEK-SCHEDULE-PD
   TYPE              = FRACTION
   DAY-SCHEDULES     = ( "Day Occup Master WD", &D, &D, &D, &D,
         "Day Occup Master WEH", &D, &D, "EL1 Bldg Occup HDD",
         "Day Occup Master WEH" )
   ..
"Week Occup Liv" = WEEK-SCHEDULE-PD
   TYPE              = FRACTION
   DAY-SCHEDULES     = ( "Day Occup Liv WD", &D, &D, &D, &D,
         "Day Occup Liv WEH", &D, &D, "EL1 Bldg Occup HDD",
         "Day Occup Liv WEH" )
   ..
"Week Occup Sm" = WEEK-SCHEDULE-PD
   TYPE              = FRACTION
   DAY-SCHEDULES     = ( "Day Occup Sm WD", &D, &D, &D, &D, "Day
Occup Sm WEH",
         &D, &D, "EL1 Bldg Occup HDD", "Day Occup Sm WEH" )
   ..
"Week Sys (RS2) Cool Liv" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Day Sys (RS2) Cool Liv WD", &D, &D, &D,
&D,
         "Day Sys (RS2) Cool Liv WEH" )
   ..
"Week Sys (RS2) Cool Mst" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Day Sys (RS2) Cool Mst WD", &D, &D, &D,
&D,
         "Day Sys (RS2) Cool Mst WEH" )
   ..
"Week Sys (RS2) Heat Liv" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
```

```
   DAY-SCHEDULES    = ( "Day Sys (RS2) Heat Liv WD", &D, &D, &D,
&D,
         "Day Sys (RS2) Heat Liv WEH" )
   ..
"Week Sys (RS2) Heat Mst" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Day Sys (RS2) Heat Mst WD", &D, &D, &D,
&D,
         "Day Sys (RS2) Heat Mst WEH" )
   ..
"Natural Ven Wk" = WEEK-SCHEDULE-PD
   TYPE             = ON/OFF/FLAG
   DAY-SCHEDULES    = ( "Natural Vent Day" )
   ..
"Vent Temp Wk" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Vent Temp Day", &D, &D, &D, &D, "Vent Temp
Day" )
   ..
"Mast Blinds week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Mast Blinds day sch", "Mast Blinds day
sch",
         "Mast Blinds day sch", "Mast Blinds day sch", "Mast Blinds
day sch",
         "Mast Blinds day sch", "Mast Blinds day sch", "Mast Blinds
day sch",
         "Mast Blinds day sch", "Mast Blinds day sch" )
   ..
"Mast Cond week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Mast Cond day sch", "Mast Cond day sch",
         "Mast Cond day sch", "Mast Cond day sch", "Mast Cond day
sch",
         "Mast Cond day sch", "Mast Cond day sch", "Mast Cond day
sch",
         "Mast Cond day sch", "Mast Cond day sch" )
   ..
"Liv Blinds summer week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Liv Blinds Summer day sch",
         "Liv Blinds Summer day sch", "Liv Blinds Summer day sch",
         "Liv Blinds Summer day sch", "Liv Blinds Summer day sch",
         "Liv Blinds Summer day sch", "Liv Blinds Summer day sch",
         "Liv Blinds Summer day sch", "Liv Blinds Summer day sch",
         "Liv Blinds Summer day sch" )
   ..
"Liv Blinds other week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Liv Blinds other day sch",
         "Liv Blinds other day sch", "Liv Blinds other day sch",
```

```
        "Liv Blinds other day sch", "Liv Blinds other day sch",
        "Liv Blinds other day sch", "Liv Blinds other day sch",
        "Liv Blinds other day sch", "Liv Blinds other day sch",
        "Liv Blinds other day sch" )
   ..
"Liv Cond summer week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Liv Cond summer day sch", "Liv Cond summer
day sch",
        "Liv Cond summer day sch", "Liv Cond summer day sch",
        "Liv Cond summer day sch", "Liv Cond summer day sch",
        "Liv Cond summer day sch", "Liv Cond summer day sch",
        "Liv Cond summer day sch", "Liv Cond summer day sch" )
   ..
"Liv Cond other week sch" = WEEK-SCHEDULE-PD
   TYPE             = MULTIPLIER
   DAY-SCHEDULES    = ( "Liv Cond other day sch", "Liv Cond other
day sch",
        "Liv Cond other day sch", "Liv Cond other day sch",
        "Liv Cond other day sch", "Liv Cond other day sch",
        "Liv Cond other day sch", "Liv Cond other day sch",
        "Liv Cond other day sch", "Liv Cond other day sch" )
   ..
"Ground T Wk Jan" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Jan" )
   ..
"Ground T Wk Feb" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Feb" )
   ..
"Ground T Wk Mar" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Mar" )
   ..
"Ground T Wk Apr" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Apr" )
   ..
"Ground T Wk May" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day May" )
   ..
"Ground T Wk Jun" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Jun" )
   ..
"Ground T Wk Jul" = WEEK-SCHEDULE-PD
   TYPE             = TEMPERATURE
   DAY-SCHEDULES    = ( "Ground T Day Jul" )
   ..
```

```
"Ground T Wk Aug" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Ground T Day Aug" )
   ..
"Ground T Wk Sep" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Ground T Day Sep" )
   ..
"Ground T Wk Oct" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Ground T Day Oct" )
   ..
"Ground T Wk Nov" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Ground T Day Nov" )
   ..
"Ground T Wk Dec" = WEEK-SCHEDULE-PD
   TYPE              = TEMPERATURE
   DAY-SCHEDULES     = ( "Ground T Day Dec" )
   ..

$ ---------------------------------------------------------
$              Annual Schedules
$ ---------------------------------------------------------

"EL1 Bldg Occup Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "EL1 Bldg Occup Wk" )
   ..
"EL1 Bldg InsLt Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "EL1 Bldg InsLt Wk" )
   ..
"EL1 Bldg Cook Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "EL1 Bldg Cook Wk" )
   ..
"EL1 Bldg Misc Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "EL1 Bldg Misc Wk" )
   ..
"DHW Eqp Res Sch" = SCHEDULE-PD
   TYPE              = FRACTION
```

```
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "DHW Eqp Res Wk" )
   ..
"ZG0-S1 (RS2) P-Inf Sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "ZG0-S1 (RS2) P-Inf Wk" )
   ..
"ZG0-S1 (RS2) C-Inf Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "ZG0-S1 (RS2) C-Inf Wk" )
   ..
"S1 Sys1 (RS2) Fan Sch" = SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "S1 Sys1 (RS2) Fan Wk" )
   ..
"S1 Sys1 (RS2) Cool Sch" = SCHEDULE-PD
   TYPE              = TEMPERATURE
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "S1 Sys1 (RS2) Cool Wk" )
   ..
"S1 Sys1 (RS2) Heat Sch" = SCHEDULE-PD
   TYPE              = TEMPERATURE
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "S1 Sys1 (RS2) Heat Wk" )
   ..
"ZG1-S1 (RS2) P-Inf Sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "ZG1-S1 (RS2) P-Inf Wk" )
   ..
"ZG1-S1 (RS2) C-Inf Sch" = SCHEDULE-PD
   TYPE              = FRACTION
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "ZG1-S1 (RS2) C-Inf Wk" )
   ..
"S2 Sys2 (RS2) Fan Sch" = SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "S2 Sys2 (RS2) Fan Wk" )
```

```
   ..
"Cust 1 Elec TOU Sched" = SCHEDULE-PD
   TYPE             = FLAG
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Cust 1 Elec TOU Seas1 Week" )
   ..
"Custom Gas Season Sched" = SCHEDULE-PD
   TYPE             = FLAG
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Custom Gas Seas1 Week" )
   ..
"Annual Occup Master" = SCHEDULE-PD
   TYPE             = FRACTION
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Occup Master" )
   ..
"Annual Occup Liv" = SCHEDULE-PD
   TYPE             = FRACTION
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Occup Liv" )
   ..
"Annual Occup Sm" = SCHEDULE-PD
   TYPE             = FRACTION
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Occup Sm" )
   ..
"Annual Sys (RS2) Cool Liv" = SCHEDULE-PD
   TYPE             = TEMPERATURE
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Sys (RS2) Cool Liv" )
   ..
"Annual Sys (RS2) Cool Mst" = SCHEDULE-PD
   TYPE             = TEMPERATURE
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Sys (RS2) Cool Mst" )
   ..
"Annual Sys (RS2) Heat Liv" = SCHEDULE-PD
   TYPE             = TEMPERATURE
   MONTH            = ( 12 )
   DAY              = ( 31 )
   WEEK-SCHEDULES   = ( "Week Sys (RS2) Heat Liv" )
   ..
"Annual Sys (RS2) Heat Mst" = SCHEDULE-PD
   TYPE             = TEMPERATURE
```

```
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "Week Sys (RS2) Heat Mst" )
   ..
"Natural Vent Sch" = SCHEDULE-PD
   TYPE              = ON/OFF/FLAG
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "Natural Ven Wk" )
   ..
"Vent Temp Sch" = SCHEDULE-PD
   TYPE              = TEMPERATURE
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "Vent Temp Wk" )
   ..
"Mast Blinds annual sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "Mast Blinds week sch" )
   ..
"Mast Cond annual sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 12 )
   DAY               = ( 31 )
   WEEK-SCHEDULES    = ( "Mast Cond week sch" )
   ..
"Liv Blinds annual sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 6, 9, 12 )
   DAY               = ( 9, 9, 31 )
   WEEK-SCHEDULES    = ( "Liv Blinds other week sch",
         "Liv Blinds summer week sch", "Liv Blinds other week sch"
)
   ..
"Liv Cond annual sch" = SCHEDULE-PD
   TYPE              = MULTIPLIER
   MONTH             = ( 6, 9, 12 )
   DAY               = ( 9, 9, 31 )
   WEEK-SCHEDULES    = ( "Liv Cond other week sch", "Liv Cond summer
week sch",
         "Liv Cond other week sch" )
   ..
"Annual Ground T" = SCHEDULE-PD
   TYPE              = TEMPERATURE
   MONTH             = ( 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 )
   DAY               = ( 31, 28, 31, 30, 31, 30, 31, 31, 30, 31, 30,
31 )
   WEEK-SCHEDULES    = ( "Ground T Wk Jan", "Ground T Wk Feb",
         "Ground T Wk Mar", "Ground T Wk Apr", "Ground T Wk May",
```

```
         "Ground T Wk Jun", "Ground T Wk Jul", "Ground T Wk Aug",
         "Ground T Wk Sep", "Ground T Wk Oct", "Ground T Wk Nov",
         "Ground T Wk Dec" )
   ..


$ ---------------------------------------------------------
$              Polygons
$ ---------------------------------------------------------

"EL1 Floor Polygon" = POLYGON
   V1               = ( 36.4, 34.45 )
   V2               = ( 48.9, 34.45 )
   V3               = ( 48.9, 0 )
   V4               = ( 85.3, 0 )
   V5               = ( 85.3, 9.85 )
   V6               = ( 90.2, 9.85 )
   V7               = ( 90.2, 34.45 )
   V8               = ( 73.5, 34.45 )
   V9               = ( 73.5, 61 )
   V10              = ( 97.1, 61 )
   V11              = ( 97.1, 84.95 )
   V12              = ( 101.05, 84.95 )
   V13              = ( 101.05, 97.1 )
   V14              = ( 73.5, 97.1 )
   V15              = ( 73.5, 92.85 )
   V16              = ( 48.9, 92.85 )
   V17              = ( 48.9, 69.55 )
   V18              = ( 36.4, 69.55 )
   V19              = ( 36.4, 92.85 )
   V20              = ( 11.8, 92.85 )
   V21              = ( 11.8, 97.1 )
   V22              = ( -15.75, 97.1 )
   V23              = ( -15.75, 84.95 )
   V24              = ( -11.8, 84.95 )
   V25              = ( -11.8, 61 )
   V26              = ( 11.8, 61 )
   V27              = ( 11.8, 34.45 )
   V28              = ( -4.9, 34.45 )
   V29              = ( -4.9, 9.85 )
   V30              = ( 0, 9.85 )
   V31              = ( 0, 0 )
   V32              = ( 36.4, 0 )
   ..
"EL1 Space Polygon 1" = POLYGON
   V1               = ( 0, 0 )
   V2               = ( 16.7, 0 )
   V3               = ( 16.7, 10.85 )
   V4               = ( 0, 10.85 )
   ..
"EL1 Space Polygon 2" = POLYGON
```

```
   V1                = ( 0, 0 )
   V2                = ( 4.9, 0 )
   V3                = ( 4.9, 13.75 )
   V4                = ( -11.8, 13.75 )
   V5                = ( -11.8, 24.6 )
   V6                = ( -11.8, 28.55 )
   V7                = ( -23.6, 28.55 )
   V8                = ( -23.6, 13.75 )
   V9                = ( -14.75, 13.75 )
   V10               = ( -14.75, 8.85 )
   V11               = ( -11.8, 8.85 )
   V12               = ( -11.8, 0 )
   ..
"EL1 Space Polygon 3" = POLYGON
   V1                = ( 0, 0 )
   V2                = ( 9.85, -0 )
   V3                = ( 9.85, 11.8 )
   V4                = ( 0, 11.8 )
   ..
"EL1 Space Polygon 1 - SMirro" = POLYGON
   V1                = ( 0, 0 )
   V2                = ( 10.85, 0 )
   V3                = ( 10.85, 16.7 )
   V4                = ( 0, 16.7 )
   ..
"EL1 Space Polygon 2 - SMirro" = POLYGON
   V1                = ( 0, 0 )
   V2                = ( 0, -11.8 )
   V3                = ( 8.85, -11.8 )
   V4                = ( 8.85, -14.75 )
   V5                = ( 13.75, -14.75 )
   V6                = ( 13.75, -23.6 )
   V7                = ( 28.55, -23.6 )
   V8                = ( 28.55, -11.8 )
   V9                = ( 24.6, -11.8 )
   V10               = ( 13.75, -11.8 )
   V11               = ( 13.75, 4.9 )
   V12               = ( 0, 4.9 )
   ..
"EL1 Space Polygon 3 - SMirro" = POLYGON
   V1                = ( 0, 0 )
   V2                = ( 11.8, 0 )
   V3                = ( 11.8, 9.85 )
   V4                = ( -0, 9.85 )
   ..


$ ---------------------------------------------------------
$              Wall Parameters
$ ---------------------------------------------------------
```

```
$ ---------------------------------------------------------
$              Fixed and Building Shades
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Misc Cost Related Objects
$ ---------------------------------------------------------


"Baseline Data" = BASELINE
   ..


$ *********************************************************
$ **                                                    **
$ **      Floors / Spaces / Walls / Windows / Doors      **
$ **                                                    **
$ *********************************************************

"EL1 Ground Flr" = FLOOR
   AZIMUTH          = 360
   POLYGON          = "EL1 Floor Polygon"
   SHAPE            = POLYGON
   FLOOR-HEIGHT     = 9.2
   SPACE-HEIGHT     = 9.2
   C-DIAGRAM-DATA   = *Bldg Envelope & Loads 1 Diag Data*
   ..
"EL1 Master Space (fG.s1)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = CONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Master"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 3623.9
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   NUMBER-OF-PEOPLE = 2
```

```
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 91
   POLYGON          = "EL1 Space Polygon 1"
   LOCATION         = FLOOR-V7
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 Flr (G.NNE1.I1)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ground Floor Cons"
   LOCATION         = BOTTOM
   ..
"EL1 North Wall (G.NNE1.E1)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 East Wall (G.NNE1.E2)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 East Win (G.NNE1.E2.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   FRAME-WIDTH      = 0
   X                = 3.13
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 4.59
   FRAME-CONDUCT    = 4.09
   ..
"EL1 Living Space (fG.s2)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = CONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Liv"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 8374.4
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
```

```
   AREA/PERSON       = 209
   POLYGON           = "EL1 Space Polygon 2"
   LOCATION          = FLOOR-V5
   C-SUB-SRC-BTUH    = ( 0, 1.7, 0 )
   C-SUB-SRC-KW      = ( 0, 0, 0 )
   C-ACTIVITY-DESC   = *Residential (Multifamily)*
   ..
"EL1 Flr (G.ESE2.I2)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ground Floor Cons"
   LOCATION          = BOTTOM
   ..
"EL1 South Wall (G.ESE2.E3)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V1
   SHADING-SURFACE   = YES
   ..
"EL1 South Win (G.ESE2.E3.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.25
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 4.4
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (G.ESE2.E4)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V2
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (G.ESE2.E4.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.32
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 13.12
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (G.ESE2.E5)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V5
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (G.ESE2.E5.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.66
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 2.62
```

```
   FRAME-CONDUCT    = 4.09
   ..
"EL1 North Wall (G.ESE2.I3)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Master Space (fG.s1)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V3
   ..
"EL1 East Wall (G.ESE2.I4)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Master Space (fG.s1)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V4
   ..
"EL1 North Wall (G.ESE2.I5)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V6
   ..
"EL1 West Wall (G.ESE2.I6)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V7
   ..
"EL1 South Wall (G.ESE2.I7)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V8
   ..
"EL1 West Wall (G.ESE2.I8)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V9
   ..
"EL1 South Wall (G.ESE2.I9)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V10
   ..
"EL1 West Wall (G.ESE2.I10)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space (fG.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V11
   ..
"EL1 South Wall (G.ESE2.I11)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fG.s3)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V12
   ..
"EL1 Small Space (fG.s3)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = UNCONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Sm"
```

```
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 2324.6
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   NUMBER-OF-PEOPLE = 2
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 58
   POLYGON          = "EL1 Space Polygon 3"
   LOCATION         = FLOOR-V4
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 Flr (G.SE3.I12)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ground Floor Cons"
   LOCATION         = BOTTOM
   ..
"EL1 East Wall (G.SE3.E6)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 South Wall (G.SE3.E7)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 South Win (G.SE3.E7.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   FRAME-WIDTH      = 0
   X                = 3.11
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 5.58
   FRAME-CONDUCT    = 4.09
   ..
"EL1 West Wall (G.SE3.I13)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fG.s3)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V3
   ..
```

```
"EL1 Mid Flrs" = FLOOR
   MULTIPLIER       = 24
   Z                = 9.2
   AZIMUTH          = 360
   POLYGON          = "EL1 Floor Polygon"
   SHAPE            = POLYGON
   FLOOR-HEIGHT     = 9.2
   SPACE-HEIGHT     = 9.2
   C-DIAGRAM-DATA   = *Bldg Envelope & Loads 1 Diag Data*
   ..
"EL1 Master Space (fM.s1)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = CONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Master"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 3623.9
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 90.6
   POLYGON          = "EL1 Space Polygon 1"
   LOCATION         = FLOOR-V7
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 North Wall (M.NNE4.E8)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 East Wall (M.NNE4.E9)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 East Win (M.NNE4.E9.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   SHADING-SCHEDULE = "Mast Blinds annual sch"
   CONDUCT-SCHEDULE = "Mast Cond annual sch"
   FRAME-WIDTH      = 0
```

```
   X                = 3.13
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 4.59
   FRAME-CONDUCT    = 4.09
   ..
"EL1 Flr (M.NNE4.I14)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Master Space (fG.s1)"
   CONSTRUCTION     = "EL1 IFlr Construction"
   INT-WALL-TYPE    = ADIABATIC
   LOCATION         = BOTTOM
   ..
"EL1 Living Space(fM.s2)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = CONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Liv"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 8374.4
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 209
   POLYGON          = "EL1 Space Polygon 2"
   LOCATION         = FLOOR-V5
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 South Wall (M.ESE5.E10)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 South Win (M.ESE5.E10.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   SHADING-SCHEDULE = "Liv Blinds annual sch"
   CONDUCT-SCHEDULE = "Liv Cond annual sch"
   FRAME-WIDTH      = 0
   X                = 0.25
   Y                = 2.47
   HEIGHT           = 4.27
```

```
   WIDTH             = 4.4
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (M.ESE5.E11)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V2
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (M.ESE5.E11.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   SHADING-SCHEDULE  = "Liv Blinds annual sch"
   CONDUCT-SCHEDULE  = "Liv Cond annual sch"
   FRAME-WIDTH       = 0
   X                 = 0.32
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 13.12
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (M.ESE5.E12)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V5
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (M.ESE5.E12.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.66
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 2.62
   FRAME-CONDUCT     = 4.09
   ..
"EL1 Flr (M.ESE5.I15)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fG.s2)"
   CONSTRUCTION      = "EL1 IFlr Construction"
   INT-WALL-TYPE     = ADIABATIC
   LOCATION          = BOTTOM
   ..
"EL1 North Wall (M.ESE5.I16)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Master Space (fM.s1)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V3
   ..
"EL1 East Wall (M.ESE5.I17)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Master Space (fM.s1)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V4
   ..
"EL1 North Wall (M.ESE5.I18)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space(fM.s2)"
```

```
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V6
   ..
"EL1 West Wall (M.ESE5.I19)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space(fM.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V7
   ..
"EL1 South Wall (M.ESE5.I20)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space(fM.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V8
   ..
"EL1 West Wall (M.ESE5.I21)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space(fM.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V9
   ..
"EL1 South Wall (M.ESE5.I22)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space(fM.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V10
   ..
"EL1 West Wall (M.ESE5.I23)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Living Space(fM.s2)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V11
   ..
"EL1 South Wall (M.ESE5.I24)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fM.s3)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V12
   ..
"EL1 Small Space (fM.s3)" = SPACE
   SHAPE            = POLYGON
   ZONE-TYPE        = UNCONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Sm"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 2324.6
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   NUMBER-OF-PEOPLE = 2
```

```
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 58
   POLYGON          = "EL1 Space Polygon 3"
   LOCATION         = FLOOR-V4
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 East Wall (M.SE6.E13)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 South Wall (M.SE6.E14)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 South Win (M.SE6.E14.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   SHADING-SCHEDULE = "Mast Blinds annual sch"
   CONDUCT-SCHEDULE = "Mast Cond annual sch"
   FRAME-WIDTH      = 0
   X                = 3.11
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 5.58
   FRAME-CONDUCT    = 4.09
   ..
"EL1 Flr (M.SE6.I25)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fG.s3)"
   CONSTRUCTION     = "EL1 IFlr Construction"
   INT-WALL-TYPE    = ADIABATIC
   LOCATION         = BOTTOM
   ..
"EL1 West Wall (M.SE6.I26)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fM.s3)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V3
   ..
"EL1 Top Flr" = FLOOR
   Z                = 230
   AZIMUTH          = 360
   POLYGON          = "EL1 Floor Polygon"
   SHAPE            = POLYGON
   FLOOR-HEIGHT     = 9.2
   SPACE-HEIGHT     = 9.2
   C-DIAGRAM-DATA   = *Bldg Envelope & Loads 1 Diag Data*
   ..
"EL1 Master Space (fT.s1)" = SPACE
```

```
   SHAPE            = POLYGON
   ZONE-TYPE        = CONDITIONED
   PEOPLE-SCHEDULE  = "Annual Occup Master"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE   = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE  = "EL1 Bldg Cook Sch"
   SOURCE-TYPE      = GAS
   SOURCE-POWER     = 3623.9
   INF-METHOD       = AIR-CHANGE
   AIR-CHANGES/HR   = 0.35
   INF-FLOW/AREA    = 0
   PEOPLE-HG-LAT    = 155
   PEOPLE-HG-SENS   = 245
   EQUIP-LATENT     = ( 0 )
   EQUIP-SENSIBLE   = ( 1 )
   SOURCE-SENSIBLE  = 0.63
   LIGHTING-W/AREA  = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON      = 90.6
   POLYGON          = "EL1 Space Polygon 1"
   LOCATION         = FLOOR-V7
   C-SUB-SRC-BTUH   = ( 0, 1.7, 0 )
   C-SUB-SRC-KW     = ( 0, 0, 0 )
   C-ACTIVITY-DESC  = *Residential (Multifamily)*
   ..
"EL1 North Wall (T.NNE7.E15)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 East Wall (T.NNE7.E16)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 East Win (T.NNE7.E16.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   FRAME-WIDTH      = 0
   X                = 3.13
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 4.59
   FRAME-CONDUCT    = 4.09
   ..
"EL1 Roof (T.NNE7.E17)" = EXTERIOR-WALL
   CONSTRUCTION     = "Roof Cons"
   LOCATION         = TOP
   ..
"EL1 Flr (T.NNE7.I27)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Master Space (fM.s1)"
   CONSTRUCTION     = "EL1 IFlr Construction"
```

```
   INT-WALL-TYPE     = ADIABATIC
   LOCATION          = BOTTOM
   ..
"EL1 Living Space (fT.s2)" = SPACE
   SHAPE             = POLYGON
   ZONE-TYPE         = CONDITIONED
   PEOPLE-SCHEDULE   = "Annual Occup Liv"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE    = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE   = "EL1 Bldg Cook Sch"
   SOURCE-TYPE       = GAS
   SOURCE-POWER      = 8374.4
   INF-METHOD        = AIR-CHANGE
   AIR-CHANGES/HR    = 0.35
   INF-FLOW/AREA     = 0
   PEOPLE-HG-LAT     = 155
   PEOPLE-HG-SENS    = 245
   EQUIP-LATENT      = ( 0 )
   EQUIP-SENSIBLE    = ( 1 )
   SOURCE-SENSIBLE   = 0.63
   LIGHTING-W/AREA   = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON       = 209
   POLYGON           = "EL1 Space Polygon 2"
   LOCATION          = FLOOR-V5
   C-SUB-SRC-BTUH    = ( 0, 1.7, 0 )
   C-SUB-SRC-KW      = ( 0, 0, 0 )
   C-ACTIVITY-DESC   = *Residential (Multifamily)*
   ..
"EL1 South Wall (T.ESE8.E18)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V1
   SHADING-SURFACE   = YES
   ..
"EL1 South Win (T.ESE8.E18.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.25
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 4.4
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (T.ESE8.E19)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V2
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (T.ESE8.E19.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
```

```
   X                 = 0.32
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 13.12
   FRAME-CONDUCT     = 4.09
   ..
"EL1 East Wall (T.ESE8.E20)" = EXTERIOR-WALL
   CONSTRUCTION      = "Ext Wall Cons"
   LOCATION          = SPACE-V5
   SHADING-SURFACE   = YES
   ..
"EL1 East Win (T.ESE8.E20.W1)" = WINDOW
   GLASS-TYPE        = "EL1 Window Type #1 GT"
   FRAME-WIDTH       = 0
   X                 = 0.66
   Y                 = 2.47
   HEIGHT            = 4.27
   WIDTH             = 2.62
   FRAME-CONDUCT     = 4.09
   ..
"EL1 Roof (T.ESE8.E21)" = EXTERIOR-WALL
   CONSTRUCTION      = "Roof Cons"
   LOCATION          = TOP
   ..
"EL1 Flr (T.ESE8.I28)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space(fM.s2)"
   CONSTRUCTION      = "EL1 IFlr Construction"
   INT-WALL-TYPE     = ADIABATIC
   LOCATION          = BOTTOM
   ..
"EL1 North Wall (T.ESE8.I29)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Master Space (fT.s1)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V3
   ..
"EL1 East Wall (T.ESE8.I30)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Master Space (fT.s1)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V4
   ..
"EL1 North Wall (T.ESE8.I31)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V6
   ..
"EL1 West Wall (T.ESE8.I32)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V7
   ..
"EL1 South Wall (T.ESE8.I33)" = INTERIOR-WALL
```

```
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V8
   ..
"EL1 West Wall (T.ESE8.I34)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V9
   ..
"EL1 South Wall (T.ESE8.I35)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V10
   ..
"EL1 West Wall (T.ESE8.I36)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Living Space (fT.s2)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V11
   ..
"EL1 South Wall (T.ESE8.I37)" = INTERIOR-WALL
   NEXT-TO           = "EL1 Small Space (fT.s3)"
   CONSTRUCTION      = "EL1 IWall Construction"
   LOCATION          = SPACE-V12
   ..
"EL1 Small Space (fT.s3)" = SPACE
   SHAPE             = POLYGON
   ZONE-TYPE         = UNCONDITIONED
   PEOPLE-SCHEDULE   = "Annual Occup Sm"
   LIGHTING-SCHEDUL = ( "EL1 Bldg InsLt Sch" )
   EQUIP-SCHEDULE    = ( "EL1 Bldg Misc Sch" )
   SOURCE-SCHEDULE   = "EL1 Bldg Cook Sch"
   SOURCE-TYPE       = GAS
   SOURCE-POWER      = 2324.6
   INF-METHOD        = AIR-CHANGE
   AIR-CHANGES/HR    = 0.35
   INF-FLOW/AREA     = 0
   PEOPLE-HG-LAT     = 155
   PEOPLE-HG-SENS    = 245
   EQUIP-LATENT      = ( 0 )
   EQUIP-SENSIBLE    = ( 1 )
   SOURCE-SENSIBLE   = 0.63
   LIGHTING-W/AREA   = ( 0.43 )
   EQUIPMENT-W/AREA = ( 1.7 )
   AREA/PERSON       = 58
   POLYGON           = "EL1 Space Polygon 3"
   LOCATION          = FLOOR-V4
   C-SUB-SRC-BTUH    = ( 0, 1.7, 0 )
   C-SUB-SRC-KW      = ( 0, 0, 0 )
   C-ACTIVITY-DESC   = *Residential (Multifamily)*
   ..
"EL1 East Wall (T.SE9.E22)" = EXTERIOR-WALL
```

```
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V1
   SHADING-SURFACE  = YES
   ..
"EL1 South Wall (T.SE9.E23)" = EXTERIOR-WALL
   CONSTRUCTION     = "Ext Wall Cons"
   LOCATION         = SPACE-V4
   SHADING-SURFACE  = YES
   ..
"EL1 South Win (T.SE9.E23.W1)" = WINDOW
   GLASS-TYPE       = "EL1 Window Type #1 GT"
   FRAME-WIDTH      = 0
   X                = 3.11
   Y                = 2.47
   HEIGHT           = 4.27
   WIDTH            = 5.58
   FRAME-CONDUCT    = 4.09
   ..
"EL1 Roof (T.SE9.E24)" = EXTERIOR-WALL
   CONSTRUCTION     = "Roof Cons"
   LOCATION         = TOP
   ..
"EL1 Flr (T.SE9.I38)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fM.s3)"
   CONSTRUCTION     = "EL1 IFlr Construction"
   INT-WALL-TYPE    = ADIABATIC
   LOCATION         = BOTTOM
   ..
"EL1 West Wall (T.SE9.I39)" = INTERIOR-WALL
   NEXT-TO          = "EL1 Small Space (fT.s3)"
   CONSTRUCTION     = "EL1 IWall Construction"
   LOCATION         = SPACE-V3
   ..


$ ***********************************************************
$ **                                                       **
$ **                 Performance Curves                    **
$ **                                                       **
$ ***********************************************************

"Residential Var Vol-Fan EIR" = CURVE-FIT
   LIBRARY-ENTRY "Residential Var Vol-Fan EIR"
   ..
"Variable Speed Drive FPLR" = CURVE-FIT
   LIBRARY-ENTRY "Variable Speed Drive FPLR"
   ..

$ ***********************************************************
$ **                                                       **
$ **               Electric & Fuel Meters                  **
```

```
$ **                                                      **
$ ********************************************************

$ --------------------------------------------------------
$              Electric Meters
$ --------------------------------------------------------

"EM1" = ELEC-METER
   TYPE             = UTILITY
   BLDG/SUB-METERS  = ( "Electric Meter Top Flr", "Electric Meter
Middle Flr",
         "Electric Meter Grd Flr", "Electric Meter Mid Master",
         "Electric Meter Mid Living", "Electric Meter Mid Small" )
   ..
"Electric Meter Top Flr" = ELEC-METER
   TYPE             = SUB-METER
   ..
"Electric Meter Middle Flr" = ELEC-METER
   TYPE             = SUB-METER
   ..
"Electric Meter Grd Flr" = ELEC-METER
   TYPE             = SUB-METER
   ..
"Electric Meter Mid Master" = ELEC-METER
   TYPE             = SUB-METER
   ..
"Electric Meter Mid Living" = ELEC-METER
   TYPE             = SUB-METER
   ..
"Electric Meter Mid Small" = ELEC-METER
   TYPE             = SUB-METER
   ..


$ --------------------------------------------------------
$              Fuel Meters
$ --------------------------------------------------------



$ --------------------------------------------------------
$              Master Meters
$ --------------------------------------------------------

"MASTER-METERS 1" = MASTER-METERS
   MSTR-ELEC-METER  = "EM1"
   MSTR-FUEL-METER  = "FM1"
   ..


$ ********************************************************
```

```
$ **                                                    **
$ **      HVAC Circulation Loops / Plant Equipment      **
$ **                                                    **
$ ******************************************************

$ ------------------------------------------------------
$              Pumps
$ ------------------------------------------------------



$ ------------------------------------------------------
$              Heat Exchangers
$ ------------------------------------------------------



$ ------------------------------------------------------
$              Circulation Loops
$ ------------------------------------------------------

"DHW Plant 1 Res Loop (1)" = CIRCULATION-LOOP
   TYPE              = DHW
   DESIGN-HEAT-T     = 120
   PROCESS-FLOW      = ( 1.32 )
   PROCESS-SCH       = ( "DHW Eqp Res Sch" )
   DHW-INLET-T-SCH   = "Annual Ground T"
   PROCESS-T         = ( 110 )
   ..


$ ------------------------------------------------------
$              Chillers
$ ------------------------------------------------------



$ ------------------------------------------------------
$              Boilers
$ ------------------------------------------------------



$ ------------------------------------------------------
$              Domestic Water Heaters
$ ------------------------------------------------------

"DHW Plant 1 Res Wtr Htr (1)" = DW-HEATER
   TYPE              = GAS
   TANK-VOLUME       = 0
   CAPACITY          = 0.067
```

```
   HIR-FPLR          = "DW-Gas-Pilotless-HIR-fPLR"
   LOCATION          = ZONE
   ZONE-NAME         = "EL1 Living Zone (fM.z2)"
   DHW-LOOP          = "DHW Plant 1 Res Loop (1)"
   C-ENERGY-FACTOR   = 0.62
   ..

$ ---------------------------------------------------------
$              Heat Rejection
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Tower Free Cooling
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Photovoltaic Modules
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Electric Generators
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Thermal Storage
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Ground Loop Heat Exchangers
$ ---------------------------------------------------------


$ ---------------------------------------------------------
$              Compliance DHW (residential dwelling units)
$ ---------------------------------------------------------


$ *********************************************************
```

```
$ **                                                        **
$ **            Steam & Chilled Water Meters                **
$ **                                                        **
$ **********************************************************

$ ----------------------------------------------------------
$              Steam Meters
$ ----------------------------------------------------------



$ ----------------------------------------------------------
$              Chilled Water Meters
$ ----------------------------------------------------------



$ **********************************************************
$ **                                                        **
$ **               HVAC Systems / Zones                     **
$ **                                                        **
$ **********************************************************

"EL1 Sys1 (RS2) (G.NNE1)" = SYSTEM
   TYPE             = RESYS2
   HEAT-SOURCE      = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO     = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T     = 110
   MIN-SUPPLY-T     = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD      = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE     = "S1 Sys1 (RS2) Fan Sch"
   FAN-CONTROL      = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF       = 0.5
   FAN-EIR-FPLR     = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOL-CAP-FT      = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR      = 0.2332
   COOL-EIR-FT      = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR    = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT       = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF          = 0.241
   COIL-BF-FFLOW    = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT       = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -14330
   HEAT-CAP-FT      = "RESYS-Heat-Cap-fEDB&OAT"
```

```
   HEATING-EIR       = 0.2827
   HEAT-EIR-FT       = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR     = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR      = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR  = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN   = 0.01
   COOL-CLOSS-MIN   = 0.01
   MSTR-ELEC-METER  = "Electric Meter Grd Flr"
   CONTROL-ZONE      = "EL1 Master Zone (fG.z1)"
   ..
"EL1 Master Zone (fG.z1)" = ZONE
   TYPE              = CONDITIONED
   FLOW/AREA         = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW    = 240
   DESIGN-HEAT-T    = 66
   HEAT-TEMP-SCH    = "Annual Sys (RS2) Heat Mst"
   DESIGN-COOL-T    = 82
   COOL-TEMP-SCH    = "Annual Sys (RS2) Cool Mst"
   THERMOSTAT-TYPE  = PROPORTIONAL
   SIZING-OPTION    = ADJUST-LOADS
   SPACE             = "EL1 Master Space (fG.s1)"
   ..
"EL1 Sys1 (RS2) (M.NNE4)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S1 Sys1 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 288000
   COOL-CAP-FT       = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR       = 0.2332
   COOL-EIR-FT       = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR    = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT        = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF           = 0.241
   COIL-BF-FFLOW    = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT        = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -343920
```

```
   HEAT-CAP-FT       = "RESYS-Heat-Cap-fEDB&OAT"
   HEATING-EIR       = 0.2827
   HEAT-EIR-FT       = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR     = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR      = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR   = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN    = 0.01
   COOL-CLOSS-MIN    = 0.01
   MSTR-ELEC-METER   = "Electric Meter Middle Flr"
   CONTROL-ZONE      = "EL1 Master Zone (fM.z1)"
   ..
"EL1 Master Zone (fM.z1)" = ZONE
   TYPE              = CONDITIONED
   FLOW/AREA         = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW     = 240
   DESIGN-HEAT-T     = 66
   HEAT-TEMP-SCH     = "Annual Sys (RS2) Heat Mst"
   DESIGN-COOL-T     = 82
   COOL-TEMP-SCH     = "Annual Sys (RS2) Cool Mst"
   SIZING-OPTION     = ADJUST-LOADS
   SPACE             = "EL1 Master Space (fM.s1)"
   ..
"EL1 Sys1 (RS2) (T.NNE7)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH   = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR   = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH     = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S1 Sys1 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC     = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOL-CAP-FT       = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR       = 0.2332
   COOL-EIR-FT       = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR     = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT        = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF           = 0.241
   COIL-BF-FFLOW     = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT        = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -14330
```

```
   HEAT-CAP-FT       = "RESYS-Heat-Cap-fEDB&OAT"
   HEATING-EIR       = 0.2827
   HEAT-EIR-FT       = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR     = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR      = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR  = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN   = 0.01
   COOL-CLOSS-MIN   = 0.01
   MSTR-ELEC-METER  = "Electric Meter Top Flr"
   CONTROL-ZONE      = "EL1 Master Zone (fT.z1)"
   ..
"EL1 Master Zone (fT.z1)" = ZONE
   TYPE              = CONDITIONED
   FLOW/AREA         = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW    = 240
   DESIGN-HEAT-T    = 66
   HEAT-TEMP-SCH    = "Annual Sys (RS2) Heat Mst"
   DESIGN-COOL-T    = 82
   COOL-TEMP-SCH    = "Annual Sys (RS2) Cool Mst"
   SIZING-OPTION    = ADJUST-LOADS
   SPACE             = "EL1 Master Space (fT.s1)"
   ..
"EL1 Sys2 (RS2) (G.ESE2)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S2 Sys2 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOL-CAP-FT       = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR       = 0.2945
   COOL-EIR-FT       = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR    = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT        = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF           = 0.241
   COIL-BF-FFLOW    = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT        = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -16550
```

```
   HEAT-CAP-FT       = "RESYS-Heat-Cap-fEDB&OAT"
   HEATING-EIR       = 0.3045
   HEAT-EIR-FT       = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR     = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR      = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR  = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN   = 0.01
   COOL-CLOSS-MIN   = 0.01
   MSTR-ELEC-METER  = "Electric Meter Grd Flr"
   CONTROL-ZONE      = "EL1 Living Zone (fG.z2)"
   ..
"EL1 Living Zone (fG.z2)" = ZONE
   TYPE              = CONDITIONED
   FLOW/AREA         = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW     = 318
   DESIGN-HEAT-T     = 66
   HEAT-TEMP-SCH     = "Annual Sys (RS2) Heat Liv"
   DESIGN-COOL-T     = 82
   COOL-TEMP-SCH     = "Annual Sys (RS2) Cool Liv"
   SIZING-OPTION     = ADJUST-LOADS
   SPACE             = "EL1 Living Space (fG.s2)"
   ..
"EL1 Sys2 (RS2) (M.ESE5)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH     = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S2 Sys2 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC     = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 288000
   COOL-CAP-FT       = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR       = 0.2945
   COOL-EIR-FT       = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR     = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT        = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF           = 0.241
   COIL-BF-FFLOW     = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT        = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -397200
```

```
   HEAT-CAP-FT       = "RESYS-Heat-Cap-fEDB&OAT"
   HEATING-EIR       = 0.3045
   HEAT-EIR-FT       = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR     = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR      = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR  = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN   = 0.01
   COOL-CLOSS-MIN   = 0.01
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   CONTROL-ZONE      = "EL1 Living Zone (fM.z2)"
   ..
"EL1 Living Zone (fM.z2)" = ZONE
   TYPE              = CONDITIONED
   FLOW/AREA         = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW    = 318
   DESIGN-HEAT-T    = 66
   HEAT-TEMP-SCH    = "Annual Sys (RS2) Heat Liv"
   DESIGN-COOL-T    = 82
   COOL-TEMP-SCH    = "Annual Sys (RS2) Cool Liv"
   SIZING-OPTION    = ADJUST-LOADS
   SPACE             = "EL1 Living Space(fM.s2)"
   ..
"EL1 Sys2 (RS2) (T.ESE8)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S2 Sys2 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOL-CAP-FT       = "RESYS-Cool-Cap-fEWB&OAT"
   COOLING-EIR       = 0.2945
   COOL-EIR-FT       = "RESYS-Cool-EIR-fEWB&OAT"
   COOL-EIR-FPLR    = "TypicalCyclingAC-EIR-fPLR"
   COOL-SH-FT        = "RESYS-Sens-Cap-fEWB&OAT"
   COIL-BF           = 0.241
   COIL-BF-FFLOW    = "RESYS-Bypass-Factor-fAirFlow"
   COIL-BF-FT        = "RESYS-Bypass-Factor-fEWB&EDB"
   HEATING-CAPACITY = -16550
```

```
   HEAT-CAP-FT      = "RESYS-Heat-Cap-fEDB&OAT"
   HEATING-EIR      = 0.3045
   HEAT-EIR-FT      = "RESYS-Heat-EIR-fEDB&OAT"
   HEAT-EIR-FPLR    = "RESYS-Heat-EIR-fPLR"
   FURNACE-HIR-FPLR = "Furnace-HIR-fPLR"
   COIL-BF-FPLR     = "RESYS-Bypass-Factor-fPLR"
   COOL-CLOSS-FPLR  = "DX-Cool-CycleLoss-fPLR"
   HEAT-CLOSS-MIN   = 0.01
   COOL-CLOSS-MIN   = 0.01
   MSTR-ELEC-METER  = "Electric Meter Top Flr"
   CONTROL-ZONE     = "EL1 Living Zone (fT.z2)"
   ..
"EL1 Living Zone (fT.z2)" = ZONE
   TYPE             = CONDITIONED
   FLOW/AREA        = 0
   OUTSIDE-AIR-FLOW = 0
   ASSIGNED-FLOW    = 318
   DESIGN-HEAT-T    = 66
   HEAT-TEMP-SCH    = "Annual Sys (RS2) Heat Liv"
   DESIGN-COOL-T    = 82
   COOL-TEMP-SCH    = "Annual Sys (RS2) Cool Liv"
   SIZING-OPTION    = ADJUST-LOADS
   SPACE            = "EL1 Living Space (fT.s2)"
   ..
"EL1 Sys3 (RS2) (G.SE3)" = SYSTEM
   TYPE             = SUM
   HEAT-SOURCE      = NONE
   SYSTEM-REPORTS   = NO
   MSTR-ELEC-METER  = "Electric Meter Grd Flr"
   ..
"EL1 Small Zone (fG.z3)" = ZONE
   TYPE             = UNCONDITIONED
   DESIGN-HEAT-T    = 66
   DESIGN-COOL-T    = 82
   SIZING-OPTION    = ADJUST-LOADS
   SPACE            = "EL1 Small Space (fG.s3)"
   ..
"EL1 Sys3 (RS2) (M.SE6)" = SYSTEM
   TYPE             = SUM
   HEAT-SOURCE      = NONE
   SYSTEM-REPORTS   = NO
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   ..
"EL1 Small Zone (fM.z3)" = ZONE
   TYPE             = UNCONDITIONED
   DESIGN-HEAT-T    = 66
   DESIGN-COOL-T    = 82
   SIZING-OPTION    = ADJUST-LOADS
   SPACE            = "EL1 Small Space (fM.s3)"
   ..
"EL1 Sys3 (RS2) (T.SE9)" = SYSTEM
```

```
   TYPE              = SUM
   HEAT-SOURCE       = NONE
   SYSTEM-REPORTS    = NO
   MSTR-ELEC-METER   = "Electric Meter Top Flr"
   ..
"EL1 Small Zone (fT.z3)" = ZONE
   TYPE              = UNCONDITIONED
   DESIGN-HEAT-T     = 66
   DESIGN-COOL-T     = 82
   SIZING-OPTION     = ADJUST-LOADS
   SPACE             = "EL1 Small Space (fT.s3)"
   ..


$ *********************************************************
$ **                                                     **
$ **                Metering & Misc HVAC                 **
$ **                                                     **
$ *********************************************************

$ ---------------------------------------------------------
$              Equipment Controls
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Load Management
$ ---------------------------------------------------------



$ *********************************************************
$ **                                                     **
$ **                    Utility Rates                    **
$ **                                                     **
$ *********************************************************

$ ---------------------------------------------------------
$              Ratchets
$ ---------------------------------------------------------



$ ---------------------------------------------------------
$              Block Charges
$ ---------------------------------------------------------

"Cust 1 Elec TOU S1-OnPk" = BLOCK-CHARGE
   BLOCK-SCH         = "Cust 1 Elec TOU Sched"
   SCH-FLAG          = 1.2
```

```
   BLOCK1-TYPE      = ENERGY
   BLOCKS-1         = ( 1 )
   COSTS-1          = ( 0.617 )
   ..
"Cust 1 Elec TOU S1-OffPk" = BLOCK-CHARGE
   BLOCK-SCH        = "Cust 1 Elec TOU Sched"
   SCH-FLAG         = 1.4
   BLOCK1-TYPE      = ENERGY
   BLOCKS-1         = ( 1 )
   COSTS-1          = ( 0.307 )
   ..
"Custom Gas Uniform Blk1" = BLOCK-CHARGE
   BLOCK-SCH        = "Custom Gas Season Sched"
   SCH-FLAG         = 1
   BLOCK1-TYPE      = ENERGY
   BLOCKS-1         = ( 1 )
   COSTS-1          = ( 6.87 )
   ..


$ ---------------------------------------------------------
$              Utility Rates
$ ---------------------------------------------------------

"Custom Elec Rate" = UTILITY-RATE
   TYPE             = ELECTRICITY
   BLOCK-CHARGES    = ( "Cust 1 Elec TOU S1-OnPk", "Cust 1 Elec TOU
S1-OffPk" )
   ..
"Custom Gas Rate" = UTILITY-RATE
   TYPE             = NATURAL-GAS
   BLOCK-CHARGES    = ( "Custom Gas Uniform Blk1" )
   ..


$ *********************************************************
$ **                                                     **
$ **                Output Reporting                     **
$ **                                                     **
$ *********************************************************

$ ---------------------------------------------------------
$              Loads Non-Hourly Reporting
$ ---------------------------------------------------------

LOADS-REPORT
   VERIFICATION     = ( ALL-VERIFICATION )
   SUMMARY          = ( ALL-SUMMARY )
   ..
```

```
$ ---------------------------------------------------------
$              Systems Non-Hourly Reporting
$ ---------------------------------------------------------

SYSTEMS-REPORT
   VERIFICATION     = ( ALL-VERIFICATION )
   SUMMARY          = ( ALL-SUMMARY )
   ..


$ ---------------------------------------------------------
$              Plant Non-Hourly Reporting
$ ---------------------------------------------------------

PLANT-REPORT
   VERIFICATION     = ( ALL-VERIFICATION )
   SUMMARY          = ( ALL-SUMMARY )
   ..


$ ---------------------------------------------------------
$              Economics Non-Hourly Reporting
$ ---------------------------------------------------------

ECONOMICS-REPORT
   VERIFICATION     = ( ALL-VERIFICATION )
   SUMMARY          = ( ALL-SUMMARY )
   ..


$ ---------------------------------------------------------
$              Hourly Reporting
$ ---------------------------------------------------------

"Hourly Report Mid Flr" = REPORT-BLOCK
   VARIABLE-TYPE    = "Electric Meter Middle Flr"
   VARIABLE-LIST    = ( 20, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12 )
   ..
"FM1 Hourly Report Block" = REPORT-BLOCK
   VARIABLE-TYPE    = "FM1"
   VARIABLE-LIST    = ( 20, 11, 3 )
   ..
"EM1 Hourly Report Block" = REPORT-BLOCK
   VARIABLE-TYPE    = "EM1"
   VARIABLE-LIST    = ( 20 )
   ..
"Hourly Report Mid Mastr" = REPORT-BLOCK
   VARIABLE-TYPE    = "Electric Meter Mid Master"
   VARIABLE-LIST    = ( 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 20 )
   ..
"Hourly Report Mid Liv" = REPORT-BLOCK
```

```
   VARIABLE-TYPE    = "Electric Meter Mid Living"
   VARIABLE-LIST    = ( 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 20 )
   ..
"Hourly Report Mid Sm" = REPORT-BLOCK
   VARIABLE-TYPE    = "Electric Meter Mid Small"
   VARIABLE-LIST    = ( 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 20 )
   ..

"Hourly Report" = HOURLY-REPORT
   LIBRARY-ENTRY "Hourly Report"
   REPORT-BLOCK     = ( "Hourly Report Mid Flr", "FM1 Hourly Report
Block" )
   ..


$ ---------------------------------------------------------
$              THE END
$ ---------------------------------------------------------

END ..
COMPUTE ..
STOP ..
```

B 2. Input Files of Energy Efficiency Measures

B 2.1. Measure 1: Replace Natural Gas Water Heater with HPWH

B 2.1.1 Existing Natural Gas Water Heater

```
$ ---------------------------------------------------------
$              Domestic Water Heaters
$ ---------------------------------------------------------

"DHW Plant 1 Res Wtr Htr (1)" = DW-HEATER
   TYPE              = GAS
   TANK-VOLUME       = 0
   CAPACITY          = 0.067
   HIR-FPLR          = "DW-Gas-Pilotless-HIR-fPLR"
   LOCATION          = ZONE
   ZONE-NAME         = "EL1 Living Zone (fM.z2)"
   DHW-LOOP          = "DHW Plant 1 Res Loop (1)"
   C-ENERGY-FACTOR   = 0.62
   ..
```

B 2.1.2 HPWH

```
$ ---------------------------------------------------------
$              Domestic Water Heaters
$ ---------------------------------------------------------

"DHW Plant 1 Res Wtr Htr (1)" = DW-HEATER
   TYPE              = HEAT-PUMP
   TANK-VOLUME       = 50
   CAPACITY          = 0.0077
   ELEC-INPUT-RATIO  = 0.375
   LOCATION          = ZONE
   ZONE-NAME         = "EL1 Living Zone (fM.z2)"
   ELEC-METER        = "Electric Meter Middle Flr"
   DHW-LOOP          = "DHW Plant 1 Res Loop (1)"
   C-ENERGY-FACTOR   = 2.4
   ..
```

B 2.2 Measure 2: Replacement with High-Efficiency Refrigerator

B 2.2.1 Equipment Power Density with Existing Refrigerator

```
$ *********************************************************
$ **                                                     **
$ **      Floors / Spaces / Walls / Windows / Doors      **
$ **                                                     **
$ *********************************************************

$ SPACE: LIVING ROOM

$ Existing Refrigerator Energy Use = 427 kWh/yr

         .
         .
         .
   EQUIPMENT-W/AREA = ( 1.7 )
         .
         .
         .
   ..
```

B 2.2.2 Equipment Power Density with New Refrigerator

```
$ *********************************************************
$ **                                                     **
$ **      Floors / Spaces / Walls / Windows / Doors      **
$ **                                                     **
$ *********************************************************

$ SPACE: LIVING ROOM

$ New Refrigerator Energy Use = 179 kWh/yr

         .
         .
         .
   EQUIPMENT-W/AREA = ( 1.3 )
         .
         .
         .
   ..
```

B 2.3 Measure 3: Apply Insulation to the Building

B 2.3.1 Exterior Wall Construction without Insulation

```
$ -----------------------------------------------------------
$              Materials / Layers / Constructions
$ -----------------------------------------------------------
"Stucco 1in (SC01)" = MATERIAL
   LIBRARY-ENTRY "Stucco 1in (SC01)"
   ..

"Conc HW 140lb 8in (CC05)" = MATERIAL
   LIBRARY-ENTRY "Conc HW 140lb 8in (CC05)"
   ..


"Ext Wall Cons Lyr" = LAYERS
   INSIDE-FILM-RES  = 0.68
   MATERIAL         = ( "Stucco 1in (SC01)", "Conc HW 140lb 8in
(CC05)",
         "Stucco 1in (SC01)" )
   THICKNESS        = ( 0.049, 0.667, 0.033 )
   ..

"Ext Wall Cons" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Ext Wall Cons Lyr"
   ..
```

B 2.3.2 Exterior Wall Construction with R-9.5 Insulation

```
$ -----------------------------------------------------------
$              Materials / Layers / Constructions
$ -----------------------------------------------------------
"Stucco 1in (SC01)" = MATERIAL
   LIBRARY-ENTRY "Stucco 1in (SC01)"
   ..

"Conc HW 140lb 8in (CC05)" = MATERIAL
   LIBRARY-ENTRY "Conc HW 140lb 8in (CC05)"
   ..

"Polystyrene 2in (IN35)" = MATERIAL
   LIBRARY-ENTRY "Polystyrene 2in (IN35)"
   ..
```

```
"Cmt Mortar 1in (CM01)" = MATERIAL
   LIBRARY-ENTRY "Cmt Mortar 1in (CM01)"
   ..

"Ext Wall Cons Lyr" = LAYERS
   INSIDE-FILM-RES  = 0.68
   MATERIAL         = ( "Stucco 1in (SC01)", "Conc HW 140lb 8in
(CC05)",
         "Stucco 1in (SC01)", "Polystyrene 2in (IN35)",
         "Cmt Mortar 1in (CM01)" )
   THICKNESS        = ( 0.049, 0.667, 0.033, 0.19, 0.016 )
   ..

"Ext Wall Cons" = CONSTRUCTION
   TYPE             = LAYERS
   LAYERS           = "Ext Wall Cons Lyr"
   ..
```

B 2.4 Measure 4: Apply Thermal Break to the Window Frame

B 2.4.1 Existing Window Frame without Thermal Break

```
$ ---------------------------------------------------------
$              Glass Types
$ ---------------------------------------------------------

"EL1 Window Type #1 GT" = GLASS-TYPE
   TYPE             = SHADING-COEF
   SHADING-COEF     = 0.87
   GLASS-CONDUCT    = 0.75
   VIS-TRANS        = 0.81
   ..
```

B 2.4.2 Existing Window Frame with Thermal Break

```
$ ---------------------------------------------------------
$              Glass Types
$ ---------------------------------------------------------

"EL1 Window Type #1 GT" = GLASS-TYPE
   TYPE             = SHADING-COEF
   SHADING-COEF     = 0.87
   GLASS-CONDUCT    = 0.54
   VIS-TRANS        = 0.81
   ..
```

B 2.5 Measure 5: Replacement with High-Efficiency Lighting

B 2.5.1 Lighting Power Density of Incandescent Lamps

```
$ *****************************************************
$ **                                                 **
$ **       Floors / Spaces / Walls / Windows / Doors      **
$ **                                                 **
$ *****************************************************
$ SPACE: LIVING ROOM, MASTER BEDROOM AND GUEST BEDROOM

          .
          .
          .
   LIGHTING-W/AREA  = ( 0.43 )
          .
          .
          .
   ..
```

B 2.5.2 Lighting Power Density of LED

```
$ *****************************************************
$ **                                                 **
$ **       Floors / Spaces / Walls / Windows / Doors      **
$ **                                                 **
$ *****************************************************
$ SPACE: LIVING ROOM, MASTER BEDROOM AND GUEST BEDROOM

          .
          .
          .
   LIGHTING-W/AREA  = ( 0.086 )
          .
          .
          .
   ..
```

B 2.6 Measure 6: Replacement with High-Efficiency HVAC Systems

B 2.6.1 Existing HVAC Systems

```
$ ***************************************************************
$ **                                                          **
$ **                HVAC Systems / Zones                      **
$ **                                                          **
$ ***************************************************************

$ NOTE*********************************************************
$ FOR MASTER BEDROOM THERMAL ZONE                             **
$ BRAND: SHARP, MODEL: KFR-25G                                **
$ SEER = 12, COOLING EIR = 0.2332                             **
$ HSPF = 11, HEATING EIR = 0.2827                             **
$ NOTE*********************************************************

"EL1 Sys1 (RS2) (M.NNE4)" = SYSTEM
   TYPE             = RESYS2
   HEAT-SOURCE      = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO     = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T     = 110
   MIN-SUPPLY-T     = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD      = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE     = "S1 Sys1 (RS2) Fan Sch"
   FAN-CONTROL      = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF       = 0.5
   FAN-EIR-FPLR     = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOLING-EIR      = 0.2332
   COIL-BF          = 0.241
   HEATING-CAPACITY = -14330
   HEATING-EIR      = 0.2827
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   CONTROL-ZONE     = "EL1 Master Zone (fM.z1)"
   ..
```

```
$ NOTE**************************************************
$ FOR LIVING ROOM THERMAL ZONE                        **
$ BRAND: SHARP, MODEL: KFR-36G/BP                     **
$ SEER = 10, COOLING EIR = 0.2945                     **
$ HSPF = 10, HEATING EIR = 0.3045                     **
$ NOTE**************************************************

"EL1 Sys2 (RS2) (M.ESE5)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD       = S-G
   VENT-TEMP-SCH     = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE      = "S2 Sys2 (RS2) Fan Sch"
   FAN-CONTROL       = FAN-EIR-FPLR
   SUPPLY-STATIC     = 1
   SUPPLY-EFF        = 0.5
   FAN-EIR-FPLR      = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOLING-EIR       = 0.2945
   COIL-BF           = 0.241
   HEATING-CAPACITY = -16550
   HEATING-EIR       = 0.3045
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   CONTROL-ZONE      = "EL1 Living Zone (fM.z2)"
   ..
```

B 2.6.2: New HVAC Systems

```
$ NOTE**************************************************
$ FOR MASTER BEDROOM THERMAL ZONE                     **
$ BRAND: HAIER, MODEL: KFR-35GW/03CAA21A              **
$ SEER = 14, COOLING EIR = 0.2300                     **
$ HSPF = 14, HEATING EIR = 0.1680                     **
$ NOTE**************************************************

"EL1 Sys1 (RS2) (M.NNE4)" = SYSTEM
   TYPE              = RESYS2
   HEAT-SOURCE       = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO      = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T      = 110
   MIN-SUPPLY-T      = 55
   MIN-OUTSIDE-AIR  = 0
```

```
   VENT-METHOD      = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE     = "S1 Sys1 (RS2) Fan Sch"
   FAN-CONTROL      = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF       = 0.5
   FAN-EIR-FPLR     = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOLING-EIR      = 0.23
   COIL-BF          = 0.241
   HEATING-CAPACITY = -16380
   HEATING-EIR      = 0.168
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   CONTROL-ZONE     = "EL1 Master Zone (fM.z1)"
   ..


$ NOTE************************************************************
$ FOR LIVING ROOM THERMAL ZONE                                  **
$ BRAND: HAIER, MODEL: KFR-35GW/03CAA21A                        **
$ SEER = 14, COOLING EIR = 0.2300                               **
$ HSPF = 14, HEATING EIR = 0.1680                               **
$ NOTE************************************************************

"EL1 Sys2 (RS2) (M.ESE5)" = SYSTEM
   TYPE             = RESYS2
   HEAT-SOURCE      = HEAT-PUMP
   BASEBOARD-SOURCE = NONE
   SIZING-RATIO     = 1.15
   RETURN-AIR-PATH  = DIRECT
   MAX-SUPPLY-T     = 110
   MIN-SUPPLY-T     = 55
   MIN-OUTSIDE-AIR  = 0
   VENT-METHOD      = S-G
   VENT-TEMP-SCH    = "Vent Temp Sch"
   NATURAL-VENT-SCH = "Natural Vent Sch"
   FAN-SCHEDULE     = "S2 Sys2 (RS2) Fan Sch"
   FAN-CONTROL      = FAN-EIR-FPLR
   SUPPLY-STATIC    = 1
   SUPPLY-EFF       = 0.5
   FAN-EIR-FPLR     = "Variable Speed Drive FPLR"
   COOLING-CAPACITY = 12000
   COOLING-EIR      = 0.23
   COIL-BF          = 0.241
   HEATING-CAPACITY = -16380
   HEATING-EIR      = 0.168
   MSTR-ELEC-METER  = "Electric Meter Middle Flr"
   CONTROL-ZONE     = "EL1 Living Zone (fM.z2)"
   ..
```

APPENDIX C

DATA FROM SIMULATED HOURLY REPORTS, ON-SITE LOGGERS AND COINCIDENT WEATHER FILE

C 1. Hourly Data from Simulation and On-Site Logger

In this study, 2012 weather data were applied to the calibrated model. In addition to the simulation, hourly indoor air temperatures were obtained for each zone. To accomplish this, portable loggers were installed in each room to measure hourly room air temperature and relative humidity. The measurements were performed from May through December of 2012. Between July and August, the apartment was renovated, so the data for this period were not used for the analysis. The following figures represent the comparison between the simulation results and the measured data, including the coincident outdoor air temperature.

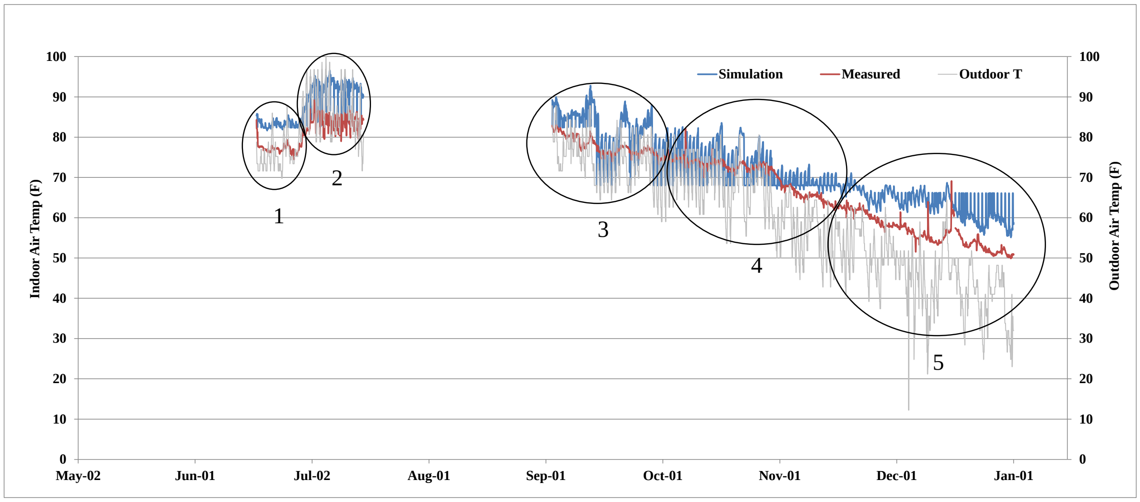

Figure C-1 Living Room Simulation Vs. Measured Indoor Air Temperature (Jun 17-Jul 15, Sep 2-Dec 31, 2012)

Figure C-1 shows the room air temperature and coincident outdoor air temperature in the living room. In this figure, the following observation can be made:

In Part 1 - the simulated temperature (T_{sim}) > the measured temperature (T_{mea})

- T_{sim} and T_{mea} had very little fluctuations

In Part 2 - T_{sim} > T_{mea}

- T_{sim} and T_{mea} both had large fluctuations

In Part 3 - T_{mea} slowly decreased from 82F to 75F

- T_{sim} had the minimum setpoint of 82F for the first part

- T_{sim} had changed setpoint for the second part

In Part 4 - T_{mea} went from 75F to 65F

- T_{sim} had minimum setpoint of 68F

In Part 5 - T_{sim} > T_{mea}

- T_{mea} decreased from 65F to 50F

- T_{sim} had the maximum setpoint of 66F

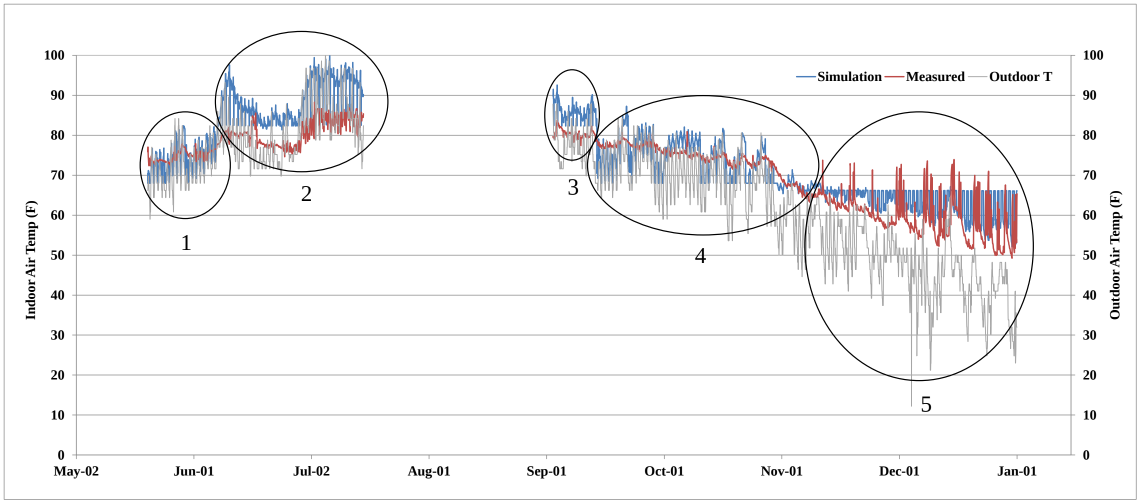

Figure C-2 Master Bedroom Simulation Vs. Measured Indoor Air Temperature (May 20-July 15, Sep 2-Dec 31, 2012)

Figure C-2 shows the room air temperature and coincident outdoor air temperature in the master bedroom. In this figure, the following observation can be obtained:

In Part 1 - T_{sim} had much bigger fluctuations than T_{mea}

In Part 2 - $T_{sim} > T_{mea}$

- T_{sim} and T_{mea} had large fluctuations

In Part 3 - $T_{sim} > T_{mea}$

- T_{sim} had the minimum setpoint of 82F

In Part 4 - T_{mea} went from 80F to 65F

- T_{sim} had minimum setpoint of 68F

In Part 5 - T_{sim} had the maximum setpoint of 66F

- T_{mea} had much bigger fluctuations than T_{sim}

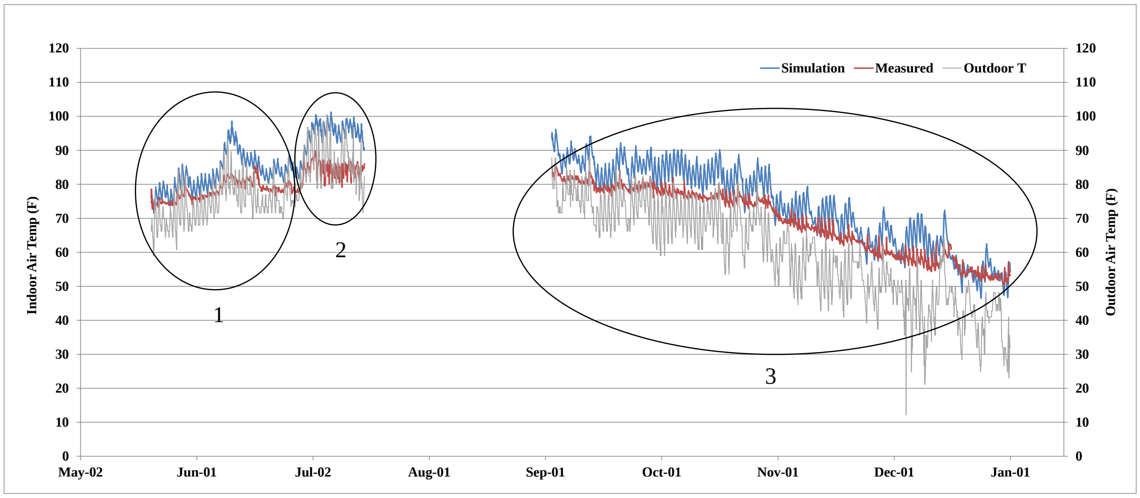

Figure C-3 Guest Bedroom Simulation Vs. Measured Indoor Air Temperature (May 20-Jul 15, Sep 2-Dec 31, 2012)

Figure C-3 shows the room air temperature and coincident outdoor air temperature in the guest bedroom. In this figure, the following observation can be obtained:

In Part 1 - $T_{sim} > T_{mea}$

- T_{sim} had bigger fluctuations than T_{mea}

In Part 2 - $T_{sim} > T_{mea}$

- T_{sim} and T_{mea} had large fluctuations

In Part 3 - $T_{sim} > T_{mea}$

- T_{sim} had bigger fluctuations than T_{mea}

The following figures had the room air temperature for each zone plotted against outdoor air temperature.

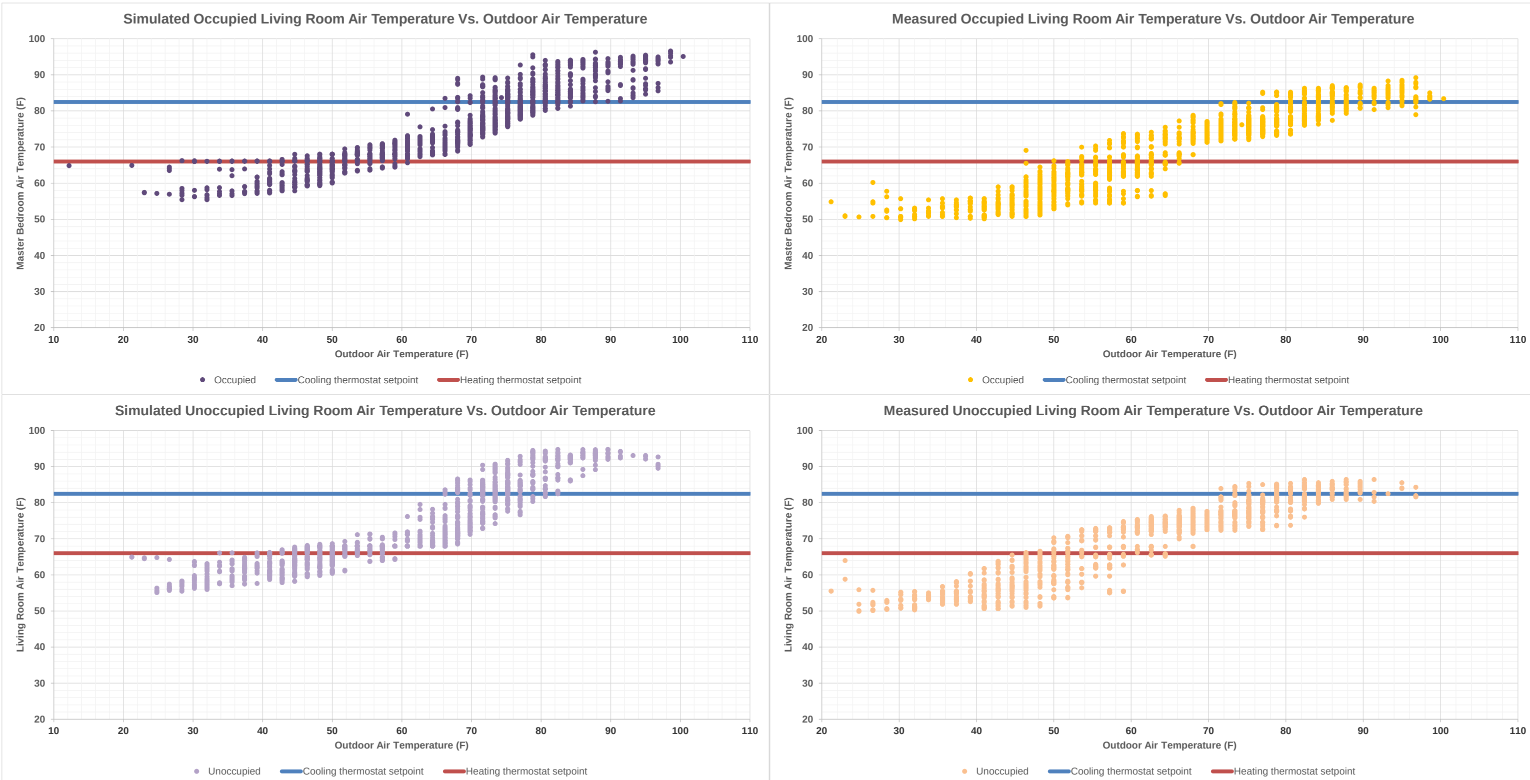

Figure C-4 Simulated Data and Measured Data Vs. Outdoor Air Temperature for Occupied/Unoccupied Living Room

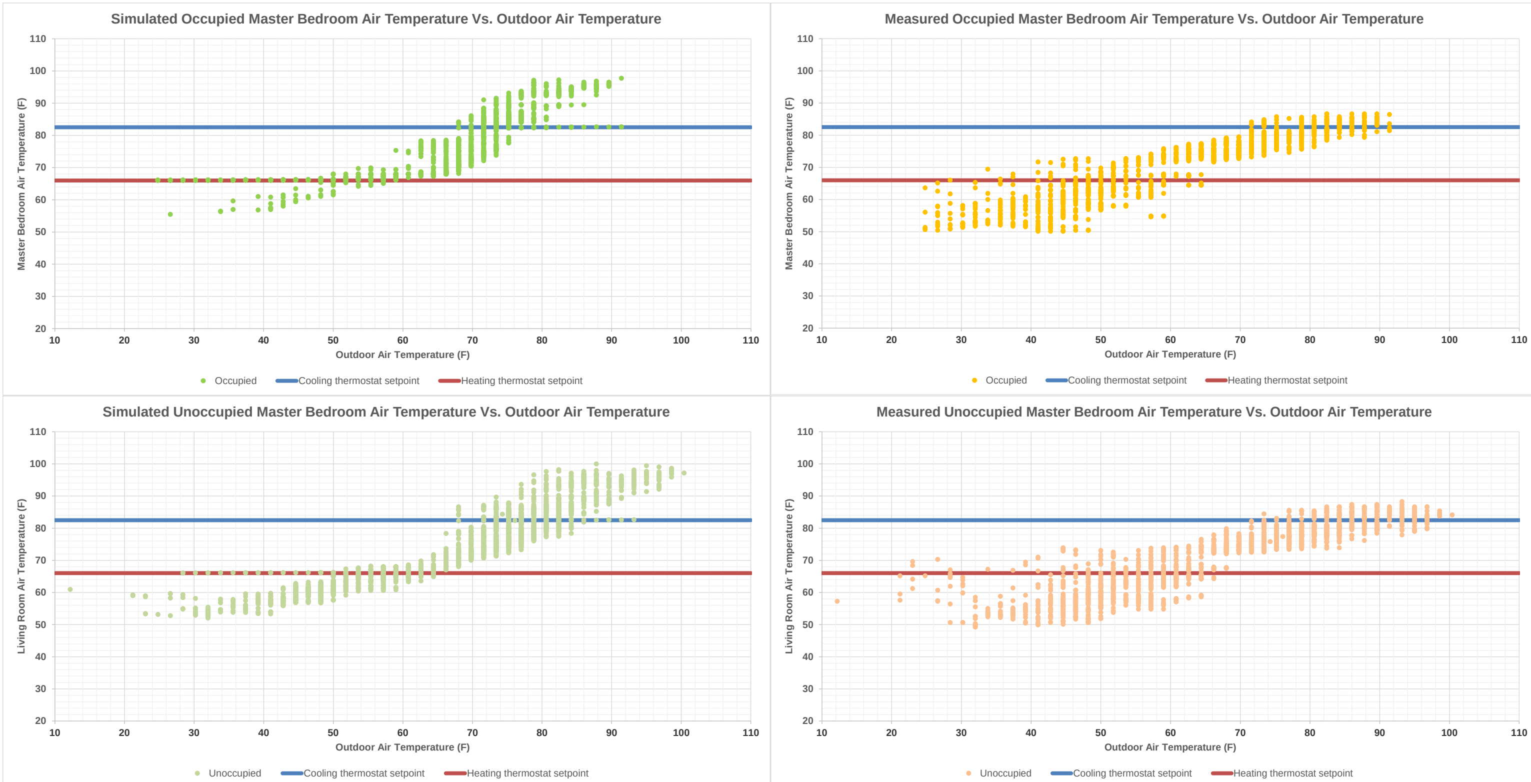

Figure C-5 Simulated Data and Measured Data Vs. Outdoor Air Temperature for Occupied/Unoccupied Master Bedroom

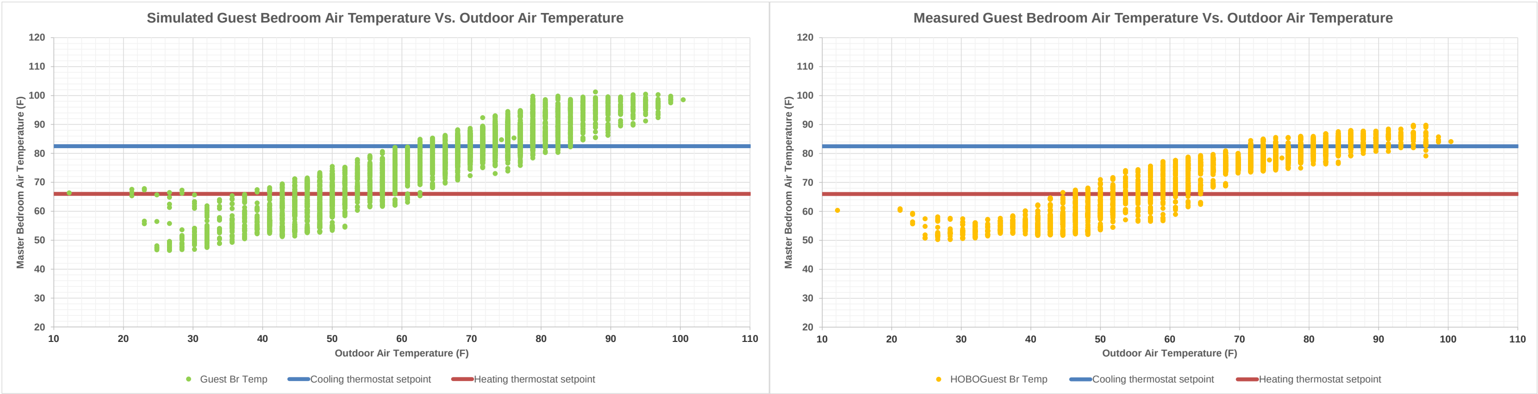

Figure C-6 Simulated Data and Measured Data Vs. Outdoor Air Temperature for Guest Bedroom

C 2 Hourly Weather Data for Shanghai

The following figures shows Shanghai weather information during the room air temperature measurement period in 2012. The weather data included solar radiation, wind speed, and ground temperature. The outdoor air temperature was plotted in previous figures. The weather data could help to analyze the household energy performance with respect to solar heat gain, wind infiltration. The monthly ground temperature was used to simulate the DHW system inlet water temperature. The weather data were extracted from 2012 Shanghai weather file.

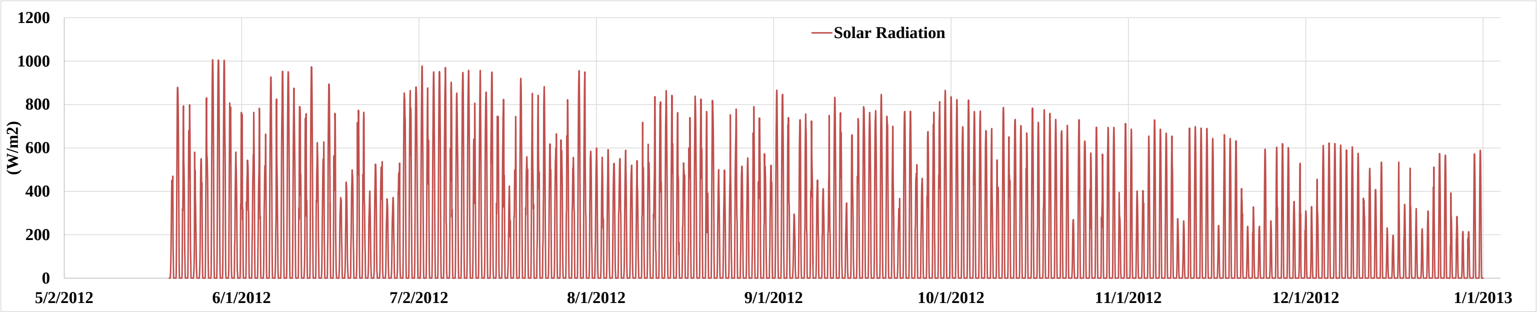

Figure C-7 Solar Radiation of Shanghai for HOBO Data Period

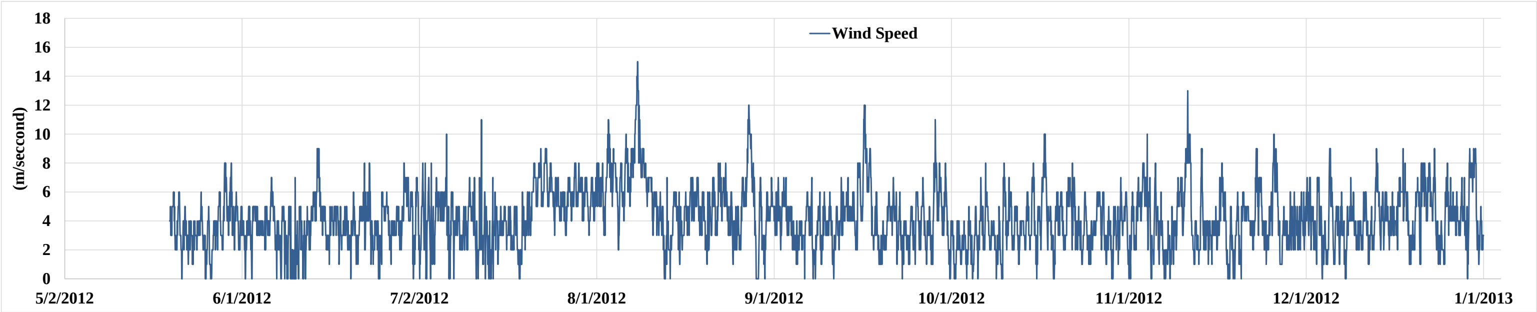

Figure C-8 Wind Speed of Shanghai for HOBO Data Period

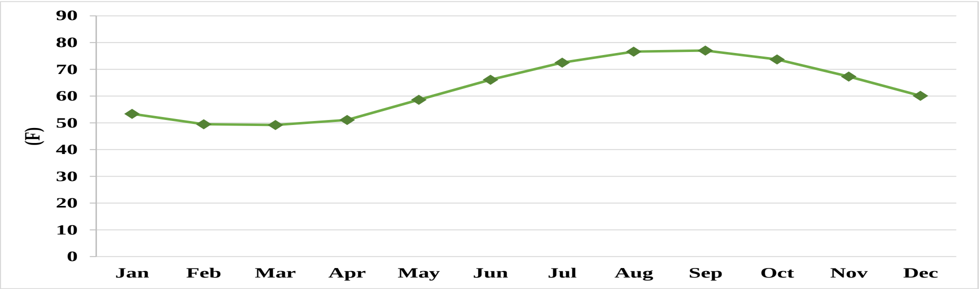

Figure C-9 Monthly Average Ground Temperature of Shanghai in 2012.

APPENDIX D

IMT COEFFICIENT OF FIVE-PARAMETER MODEL FOR THE BASE-CASE APARTMENT

This section shows the 5P model for electricity use calibration. In this analysis, a model was generated with the Inverse Model Toolkit (IMT) in ASHRAE Research Project 1050 (Kissock et al., 2004). The 2011 utility bill for the apartment were used to generate the model. Since the apartment had both cooling and heating loads, the model has 5 parameters (5P) to represent the annual energy performance as a function of outdoor air temperature. The monthly utility data (except February) was used to create the model, which had a high R^2 and a low CV(RMSE). According to the 5P model, the apartment has heating loads when outdoor air temperature drops below 62.5F (X_{cp1}), and cooling loads when outdoor air temperature surpasses 79F (X_{cp2}). The average daily energy use without heating or cooling is 5.4 Wh/day-ft^2 (Y_{cp}).

```
*******************************************
ASHRAE INVERSE MODELING TOOLKIT (1.9)
*******************************************
 Output file name = IMT.Out

*******************************************
 Input data file name = MonthlyDat.dat
 Model type =        5P
 Grouping column No =   5
 Value for grouping =   1
 Residual mode =       1
 # of X(Indep.) Var =   1
 Y1 column number =    8
 X1 column number =  9
 X2 column number =  0 (unused)
 X3 column number =  0 (unused)
 X4 column number =  0 (unused)
 X5 column number =  0 (unused)
 X6 column number =  0 (unused)
```

```
*******************************************
Regression Results
--------------------------------------
   N =    11
--------------------------------------
   R2 =    0.975
--------------------------------------
  AdjR2 =    0.975
--------------------------------------
  RMSE =    0.4652
--------------------------------------
 CV-RMSE =    6.021%
--------------------------------------
   p =    0.206
--------------------------------------
   DW =    1.307 (p>0)
--------------------------------------
  Xcp1 =    62.5354 (     1.6243)
--------------------------------------
  Xcp2 =    78.7979 (     1.6243)
--------------------------------------
   Ycp =    5.4154 (     0.1978)
--------------------------------------
   LS =    -0.3338 (     0.0189)
--------------------------------------
   RS =    0.6092 (     0.0777)
--------------------------------------
```

APPENDIX E

DIVISION OF RESEARCH

Human Subjects Protection Program

TEXAS A&M UNIVERSITY

June 5, 2014

Hongyun Zhou
Graduate Student
Department of Architecture
Texas A&M University
College Station, TX 77843

Dear Ms. Zhou,

Thank you for your inquiry to the Texas A&M University IRB regarding your thesis project. The TAMU Human Subjects Protection Program has reviewed the information you have provided regarding this project. Your case study research is to analyze energy use (electricity, natural gas) for a single apartment. You need some information from the residents such as when they turn on lights, use domestic appliances, and turn on their air-conditioning systems. The apartment for your study is your home, the residents are your parents, and you called them for this information. Given this information about the work, the research you will be conducting does not match the definition of human subjects research according to the Federal Regulations. Therefore, this research does not need to be submitted for review by the TAMU IRB.

Please contact TAMU Human Subjects Protection Program with additional questions. Best wishes for your endeavors.

Sincerely,

Catherine L. Higgins, Ph.D.
Manager, Human Subjects Protection Program
Member, TAMU Institutional Review Board
979-458-4117
clhiggins@tamu.edu

750 Agronomy Road, Suite 3501
1186 TAMU
College Station, TX 77843-1186

Tel. 979.458.1467 Fax. 979.862.3176
http://rcb.tamu.edu